EndResult®

Add-ins for Microsoft® Excel
English Unit Edition

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Add-ins for Microsoft® Excel Ver. 5, 7, 97, 2000, & 2002 (XP) for Windows™

EndResult®

Table of Contents

Overview

The EndResult® Steam Plant Engineering Tools add-ins contain 169 functions which you can use just like built-in Microsoft® Excel functions. You can use the EndResult® add-in to extend the capabilities of Microsoft® Excel Versions 5, 7, 97, 2000, and 2002 (XP).

After the EndResult® Steam Plant Engineering Tools add-ins are loaded, the EndResult® functions work exactly like Microsoft® Excel's built-in functions. EndResult® functions can be used in any number of cells, worksheets, and macros and can even be combined with functions from other add-ins.

An equals sign ("=") should be the first character in any cell containing an EndResult® function. In the example below, two EndResult® functions and an Excel *IF* Function are used to determine a maximum value for enthalpy:

```
=IF($B$55>3208.235,CRTPT2H($B$55,1500),STMPT2H($B$55,1500))
```

Each EndResult® function is described in this chapter and will appear in capital letters. Arguments to each EndResult® function appear in italics but actual arguments used in examples are not italicized.

For your convenience, EndResult® functions are provided for both English engineering units and metric engineering units.

English Functions (Do not begin with X)

EndResult® functions which use English engineering units DO NOT begin with the letter "x". For example, to compute the enthalpy of steam at 2500 Psia and 900°F and, you would enter =STMPT2H(2500,900) and your result would be 1386.688 Btu/Lb. Notice that both the inputs and the result are in English engineering units.

Quantity	English units	Metric units
Conductivity	Btu/Ft Hr °F	W/m-K
Density	Lb/Cuft	kg/m^3
Energy	MBtu/Hr	MJ/Hr
Enthalpy	Btu/Lb	kJ/kg
Entropy	Btu/Lb °R	kJ/kg-K
Mass flow	Lb/Hr	kg/Hr
Pressure	Psia	•kPa
Specific heat	Btu/Lb °F	kJ/kg-K
Temperature	°F	°C
Viscosity	Lb/Sec-ft	Pa-sec

• Throughout the *EndResult* software, pressures in "kPa" are assumed to be *absolute* unless "kPa gage" is specified.

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Metric Functions (Begin with X)

EndResult® functions which use metric engineering units begin with the letter “X”. For example, to compute the enthalpy of steam at 13700 kPa and 510°C, you would enter =XSTMPT2H(13700,510) and your result would be 3355.246 kJ/kg. Notice that both the inputs and the result are in metric engineering units.

The EndResult® ERUNITS function described on page “EREXCEL-45” provides you with a convenient way to perform many unit conversions.

EndResult® functions require any percentage (e.g. percent quality, relative humidity, etc.) to be entered into the worksheet as a number between 0 and 1. If desired, you can select **“0.00%”** from the **Format Number…** list box to get Microsoft® Excel to display the number as a percent (or use the quick key combination **<CTRL-%>**).

Remember that Microsoft® Excel allows you to adjust the number of displayed digits by:

(1) Adjusting the cell width of cells which have been formatted using the **Format Number… “General”** command.

(2) Specifying the number of decimal places when formatting a range of cells using a fixed “0.00”, scientific “0.00E+00”, or percent “0.00%” format.

Several EndResult® functions allow you to enter ‘Not Applicable’ for one or more arguments in a function. As shown by the examples below, this can be accomplished by entering either NA(), #N/A, or by leaving the argument blank.

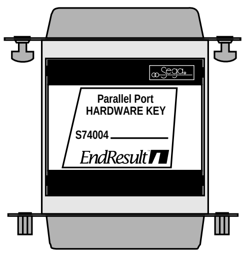
=XRADLOSS (1.5E+8,4,101000,30.5,10,1706,3396,1209,10200000,3023,3536,9250000,NA(),NA(),NA())

=XRADLOSS (1.5E+8,4,101000,30.5,10,1706,3396,1029,10200000,3023,3536,9250000,#N/A,#N/A,#N/A)

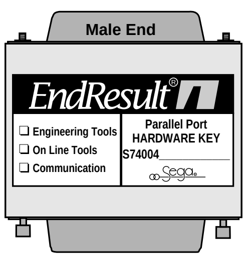
=XRADLOSS (1.5E+8,4,101000,30.5,10,1706,3396,1029,10200000,3023,3536,9250000,,,)

Attaching the EndResult® Hardware Key

Male End of the hardware key plugs into the computer parallel port.



EndResult
hardware key
Style One



EndResult
hardware key
Style Two

The EndResult® **hardware key** sent with your EndResult® software should support the Steam Plant Engineering Tools Add-in in addition to all other EndResult® add-ins which you have purchased.

The hardware key should be attached to the parallel printer port (either LPT1, LPT2, or LPT3) of your IBM PC/XT/AT, PS/2 or fully compatible computer. *If you are running EndResult® under Microsoft® Windows NT™, be sure to follow the instructions which start on page "Installation-10".*

If the hardware key is incorrect or missing, the following differences will be apparent:

(1) When the EndResult® add-ins are loaded, a pop-up window will notify you that the hardware key is missing.

(2) All EndResult® functions within the Excel worksheet will return "#Key?".

If you have purchased the EndResult® Steam Plant Engineering Tools Add-in and you are still having problems with your hardware key, please contact Sega Inc. immediately.

If the hardware key is incorrect or missing for more than 15 seconds, any subsequent attempt to recalculate an EndResult® function will return "#KEY?".

After the hardware key is attached, you can eliminate key errors in the worksheet by either:

(1) pressing F9 to recalculate the worksheet.

(2) moving the pointer to each ("#Key?") cell and pressing F2 followed by <ENTER> to recalculate the cell.

(3) moving the pointer to inputs in the calculation chain and pressing F2 followed by <ENTER> to recalculate all cells which are dependent on the input.

If any EndResult® function is displaying an error message (e.g. "#N/A", "#KEY?", etc.), you can display a brief explanation for the error by moving the cell pointer to the cell containing the error message and selecting "EndResult®" from the Microsoft® Excel Help menu.

Note: The absence of the hardware key only affects EndResult® functions. Microsoft Excel (as well as add-ins sold by other vendors) will still function normally with or without the EndResult® hardware key.

Since the Steam Plant Engineering Tools Add-in is not copy protected, you may make the number of backup copies of the add-in stipulated in the preceding Software License Agreement. However, since only one key is provided with each original copy, only one copy of the add-ins can be run at any one time.

Installing the Add-in Files on Your Hard Disk

Please reference the latest readme file for installation instructions. This can be found at www.endresult.com. Also available for download are the Examples Spreadsheets and the Pre-Defined Spreadsheet Solutions.

Identifying the Cause of an Error

If a cell containing an EndResult® Steam Plant Engineering Tools function displays an error message (e.g., “#N/A”, “#KEY?”, etc.), you can move the cell pointer to the cell and select **“EndResult®”** from the Microsoft® Excel **Help** menu to display a brief explanation for why the error occurred. Remember that you can select **“EndResult®”** from the **Help** menu by using the mouse or by pressing **<ALT>, “H”, “R”** on the keyboard.

As shown in the example below, the error message displays the name of the EndResult® Steam Plant Engineering Tools function which is evoking an error and a brief explanation for why the error occurred. If the error is being caused by the value of one or more arguments being passed to the function, the error message will identify the argument(s) which are responsible for the error.

- If you enter a number which is above the maximum allowable, the function will return a “#N/A” error. As shown in the picture below, you can display the maximum on your screen by moving your pointer to the cell and selection **“EndResult®”** from the Microsoft® Excel **Help** menu.

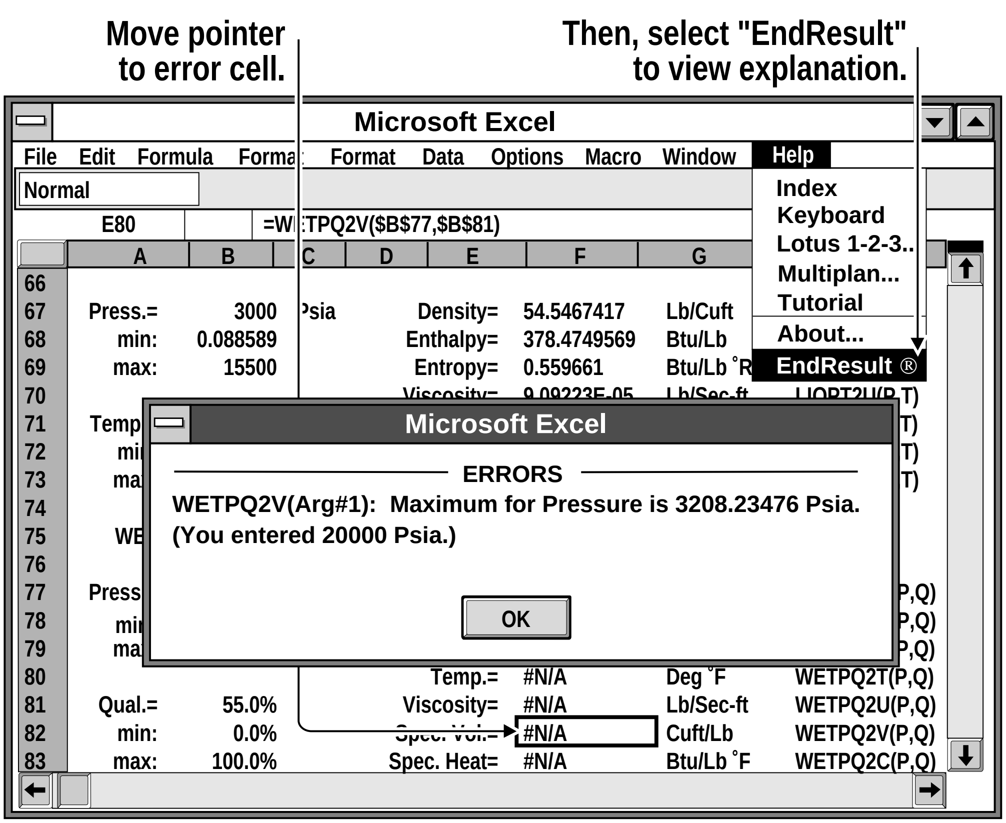
Information for users of Microsoft Excel Version 3.0

"EndResult®" will not appear in the Excel **Help** menu if you have selected **"Short Menus"**.

If desired, you can select **"Full Menus"** from the Excel **"Options"** menu to re-enable the **Help "EndResult®"** menu item.

Selecting **"EndResult®"** from the Excel **Help** menu will clear the **"Move Selection after Enter"** check box.

If desired, you can select **"Workspace..."** from the Excel **Options** menu to re-enable this item.



If you enter a number which is below the minimum allowable, the function will return a "#N/A" error. If desired, you can display the minimum on your screen by moving your pointer to the cell and selecting **"EndResult®"** from the Microsoft® Excel **Help** menu.

- If the hardware key is incorrect or missing, the function will return a "#KEY?" error. You can determine if the hardware key is causing the problem by moving your pointer to the cell and selecting **"EndResult®"** from the Microsoft® Excel **Help** menu.
- If you select **"EndResult®"** from the Microsoft® Excel **Help** menu while your pointer is on a cell which does not contain an error (or warning), the EndResult® pop-up window wil tell you that there is "No Error or Warning in this Cell!".
- If you select **"EndResult®"** from the Microsoft® Excel **Help** menu while your pointer is on a cell which does not contain an EndResult® function, the pop-up window will tell you that there is "No EndResult® function in this cell!".
- If cells with EndResult® functions display "#REF!" or if you select **"EndResult®"** from the Microsoft® Excel **Help** menu and a pop-up window *does not* appear, the EndResult® add-in is not properly installed.
- You cannot access **Help EndResult®** messages if your document is protected *AND* your cell pointer is on a locked cell. You must either unprotect the document or unlock the cell before selecting **"EndResult®"** from the Microsoft® Excel **Help** menu.

Using Warnings

EndResult® functions can also provide information in the form of "Warnings". Whereas an *error* causes an EndResult® function to return an error message (e.g., "#N/A", "#KEY?", etc.), a *warning* still allows the function to compute a result.

To determine if an EndResult® function is causing a *warning*, move the cell pointer to the cell and select **"EndResult®"** from the **Help** menu. This will cause either a list of *warnings* or the message "No error or warning in this cell" to appear. Remember that you can select **"EndResult®"** from the **Help** menu by using the mouse or by pressing **<ALT>, "H", "R"** on the keyboard.

Lastly, if an EndResult® function evokes one or more errors and one or more warnings, the errors will always be listed first.

Add-in Functions

Mixed Gas Thermo-Physical Property Add-in

The results computed by the "Mixed Gas Thermo-Physical Properties" add-in are based on formulations from the following sources:

- The ultimate analysis computation method, the molecular weights, and the energy conversion constants used by this add-in are based on data and equations found in *Steam/Its Generation and Use*[4].
- The gas compressibility is computed using the Redlich-Kwong method.
- Viscosity is computed using "Arnolds Correlation" and the square root rule.
- Critical properties computed by this add-in are based on formulations found in the *Flow Measurement Engineering Handbook*[5].
- Enthalpy and entropy of water vapor are from the *ASME Steam Tables*[6].
- Additional gas properties are computed from formulations found in the *Physical and Thermodynamic Properties of Pure Chemicals*[7], *Thermodynamics*[8], *Fan Engineering*[9], and the ASHRAE[10] Psychrometric Charts.

Both the **COMBCYC.XLS** and **GASTURB.XLS** worksheets (provided in the www.endresult.com **Pre-defined Spreadsheet Solutions** download file) demonstrate how the mixed gas thermo-physical property add-in functions can be combined with other functions to compute boiler efficiency, gas turbine heat rate, and properties of the combustion air and flue gas.

For a working example of all of the mixed gas thermo-physical property functions shown below, load the **MIXGAS.XLS** worksheet (provided in the www.endresult.com **Examples** download file). The **MIXGAS.XLS** worksheet provides an easy way to familiarize yourself with each EndResult® function. You can experiment with each function by entering numbers into the highlighted unprotected user-input cells.

The **MIXGAS.XLS** worksheet from your EndResult® **Examples** download file is shown below and on the following pages. The name of each argument appears in cells A1 to A13 and an example value for each argument appears in cells B1 to B13. Valid ranges for each input are listed in column C.

The second argument can Be either Temperature, Enthalpy, or Entropy. See the following page For more information →

	A	B	C
1	**Pressure**	**14.696**	**(from 2.25E-14 to 3208.235 Psia)**
2	**Temperature**	**364.0922**	**(from -425°F to 4000°F)**
3			

4 Babcock & Wilcox. *Steam/Its Generation and Use,* 40th Edition, (New York: Babcock & Wilcox Company, 1992), Section 6.
5 Richard W. Miller. *Flow Measurement Engineering Handbook*, (New York: McGraw-Hill Book Company, 1983).
6 International Formulation Committee, "*The 1967 Formulation for Industrial Use*", *ASME Steam Tables*, Fifth Edition, (New York: American Society of Mechanical Engineers, 1873), Appendix 1, pages 11-29.
7 T.E. Daubert and R.P. Danner, ed., *Physical and Thermodynamic Properties of Pure Chemicals, Data Compilation,* (New York: Hemisphere Publishing Corporation, 1991).
8 Faires, *Thermodynamics* (New York: The MacMillan Company, 1957).
9 *Fan Engineering*, (New York: Buffalo Forge Company, 1983).
10 ASHRAE Psychrometric Chart No. 1 & No. 2, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1963.

The items in rows 4 to 13 are optional. If you omit any of these items, the default value shown to the left of each row will be used.

		A	B	C
(default is Temperature) →	4	**Second Argument**	**Temperature**	**(Temperature, Enthalpy, or Entropy)**
(default is 60°F) →	5	**Reference Temperature**	**60**	**(from -425°F to 4000°F)**
(default is 14.73 Psia) →	6	**Reference Pressure**	**14.73**	**(from 2.25E-14 to 3208.235 Psia)**
(applies to enthalpy and entropy, default is 32.018°F) →	7	**Zero Enthalpy Temperature**	**32.018**	**(from -425°F to 4000°F)**
(default is Volume) →	8	**Gas Mixture Percent by**	**Volume**	**(Weight or Volume)**
	9	**Carbon Dioxide**	**11.4940%**	**(from 0% to 100% by Volume or Weight)**
Use a formula like SUM($B$9 : $B$13) to ensure that 100% of the gas constituents have been specified.	10	**Atmospheric Nitrogen**	**74.0720%**	**(from 0% to 100% by Volume or Weight)**
	11	**Oxygen**	**6.4000%**	**(from 0% to 100% by Volume or Weight)**
	12	**Sulfur Dioxide**	**0.1320%**	**(from 0% to 100% by Volume or Weight)**
	13	**Water Vapor**	**7.9020%**	**(from 0% to 100% by Volume or Weight)**
	14			
	15	**Ultimate Analysis Carbon GAS2CAR**	**4.683946%**	**% by Wt**

Each mixed gas thermo-physical property function requires the same four arguments as the GAS2CAR function in cell B15. To compute the **Ultimate Analysis Carbon**, cell B15 contains the formula =GAS2CAR($B$1,$B$2,$A$4:$A$13,$B$4:$B$13).

Argument #1 The first argument is the pressure of the gas mixture in Psia.

Argument #2 The "Second Argument" identifier shown above in row 4 specifies whether the second argument is temperature, enthalpy, or entropy.

If you specify Second Argument as:	**Enter a value for the 2nd argument which is:**
Temperature	from -425°F to 4000°F
Enthalpy	from -1300 to 3400 Btu/Lb.
Entropy	from -1.27 to 2.21 Btu/Lb °R

Argument #3 The third argument is the *Identifier Range*. In the example spreadsheet above the *Identifier Range* extends from cell A4 to A13 and includes five gases. The *Identifier Range* must be a single column wide. As a minimum, the *Idententfier Range* must include from 1 to 37 of the following gases:

Acetylene, Air, Ammonia, Argon, Benzene, Carbon Dioxide, Carbon Monoxide, Ethane, Ethyl Alcohol, Ethylene, Hydrogen Gas, Hydrogen Sulfide, i-Butane, 1-Butene, i-Pentane, Methane, Methyl Alcohol, n-Butane, cis-2-Butene, n-Heptane, n-Hexane, n-Nonane, n-Octane, n-Pentane, 1-Pentene, Neopentane, Nitrogen, Atmospheric Nitrogen, Oxygen, Propane, Propylene, Sulfur Dioxide, Toluene, o-Xylene, m-Xylene, p-Xylene, Water Vapor.

Identifiers can be abbreviated to as few as 3 characters (e.g. "Ben" for "Benzine"), as long as enough characters of each identifier are entered to

distinguish it from other identifiers. Each identifier may be left, center, or right justified. Although capitalization is not significant, hyphens should be included where shown. An *Identifier* can be followed by a comment as long as a non-alphanumeric character (e.g. comma, semicolon, parenthesis, colon, …) precedes the comment. The *Identifier* and *Value Ranges* can include blank rows.

Argument #4 The fourth argument is the *Value Range*. In the example spreadsheet above the *Value Range* extends from cell B4 to B13 and includes five gases. The *Value Range* must be a single column wide.

If your identifier is a gas, its percent by volume or weight should be entered into the worksheet as a number from 0 to 1. If desired, you can select **"0.00%"** from the **Format Number…** list box to get Microsoft® Excel to display the number as a percent (or use the quick key combination **<CTRL-%>**). Omitted gases are automatically assigned zero percent.

WARNING:
Under conditions of very low temperature and/or high pressure one or more of the gas constituents may become liquid. Under marginal conditions, you should use the GAS2ZRA function described on page "EREXCEL-14" to insure that the answer returned by the add-in is valid. If the GAS2ZRA function tells you that a constituent in the gas mix is in the liquid state at the zero enthalpy, reference, and/or actual conditions, the results computed by the add-in may not be valid. **The "ZR" exception for "Water Vapor":** As shown in the example worksheet on page "EREXCEL-14", cell F78 contains the formula =GAS2ZRA($B$1, $B$2, $A$4 : $A$13, $B$4 : $B$13, "Water Vapor"). For most common combustion air and flue gas applications, if you ask the GAS2ZRA function for the state of H_2O, the letters returned by the GAS2ZRA function will include "Z" and "R" indicating that H_2O is a liquid at both the zero enthalpy conditions and reference conditions. Since the mixed gas add-in is linked to the ASME steam tables, the enthalpy and entropy contribution from H_2O should still be correct even if H_2O is a liquid at these conditions. However, if one of the letters returned by the GAS2ZRA function is a letter "A" (i.e. actual conditions), the results computed by the add-in may not be valid.

Notice to users of previous versions of the EndResult add-ins.
The GAS2H2O function for computing Ultimate Analysis Moisture is obsolete and should not be used. To insure compatibility with worksheets developed using previous versions of EndResult, the GAS2H2O function will ALWAYS return zero and will not return an error. Additionally, the "Analysis Compensated (or Uncompensated)" option is obsolete and should not be used. To insure compatibility with worksheets developed using previous versions of EndResult, any appearance of "Analysis Compensated (or Uncompensated)" within a mixed gas calculation will be ignored and the analysis will ALWAYS be uncompensated.

To compute the ultimate analysis carbon, cell B15 contains the formula =GAS2CAR($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2CAR function uses the four arguments described on pages “EREXCEL-8” and "ÉREXCEL-9”. The results in cells B16 through B20 are computed in a similar manner using the same arguments and the function indicated in column A.[11]

	A		B	C
15	**Ultimate Analysis Carbon**	**GAS2CAR**	**4.683946%**	**% by Wt**
16	**Ultimate Analysis Hydrogen**	**GAS2HYD**	**.540460%**	**% by Wt**
17	**Ultimate Analysis Oxygen**	**GAS2OXY**	**23.859626%**	**% by Wt**
18	**Ultimate Analysis Nitrogen**	**GAS2NIT**	**70.772360%**	**% by Wt**
19	**Ultimate Analysis Sulfur**	**GAS2SUL**	**0.143609%**	**% by Wt**
20	**Ultimate Analysis Total**	**GAS2TOT**	**100.000000%**	**% by Wt**

To compute the higher heating value, cell B22 contains the formula =GAS2HHVSCF($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2HHVVSCF function uses the four arguments described on pages "EREXCEL-8” and “EREXCEL-9”. The results in cells B23 through B28 are computed in a similar manner using the same arguments and the function indicated in column A.

		A		B	C
Standard Conditions→	22	**Higher Heating Value (Reference, SCF)**	**GAS2HHVSCF**	**0**	**Btu/Cuft**
Actual Conditions→	23	**Higher Heating Value (ACF)**	**GAS2HHVACF**	**0**	**Btu/Cuft**
	24	**Higher Heating Value**	**GAS2HHV**	**0**	**Btu/Lb**
Standard Conditions→	25	**Lower Heating Value (Reference, SCF)**	**GAS2LHVSCF**	**0**	**Btu/Cuft**
Actual Conditions→	26	**Lower Heating Value (ACF)**	**GAS2LHVACF**	**0**	**Btu/Cuft**
	27	**Lower Heating Value**	**GAS2LHV**	**0**	**Btu/Lb**
	28	**Theoretical Air per Lb As Fired Fuel**	**GAS2AIR**	**0**	**Lb/Lb**

11 Hint: To quickly enter the cell formulas in cells B15 to B20, enter the GAS2CAR function in cell B15, then copy it to cells B16 to B20, and then change each cell to the correct function. Correct use of absolute references (e.g. $B$2) and relative references (e.g. B2) will ensure that copied formulas have the desired references.

To compute the reduced temperature, cell B30 contains the formula =GAS2RT($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2RT function uses the four arguments described on pages “EREXCEL-8” and "ÉREXCEL-9”. The remaining results in cells B31 through B35 are computed in a similar manner using the same arguments and the function indicated in column A.[12]

	A		B	C
30	**Reduced Temperature**	**GAS2RT**	**2.4090887**	
31	**Reduced Pressure**	**GAS2RP**	**1.863681E-2**	
32	**Critical Temperature**	**GAS2TC**	**341.93934**	**°R**
33	**Critical Pressure**	**GAS2PC**	**788.54691**	**Psia**
34	**Critical Volume**	**GAS2VC**	**4.821743E-02**	**Cuft/Lb**
35	**Critical Compressibility**	**GAS2ZC**	**0.2846665**	**[Zc]**

The following 6 items are only results if water vapor is present, otherwise these items will return “#N/A”. To compute the water vapor partial pressure, cell B37 contains the formula =GAS2H2OPP($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2H2OPP function uses the four arguments described on pages “EREXCEL-8” and “EREXCEL-9”. The remaining results in cells B38 through B42 are computed in a similar manner using the same arguments and the function indicated in column A.

	A		B	C
37	**Water Vapor Partial Pressure**	**GAS2H2OPP**	**1.161278**	**Psia**
38	**Water Vapor ASME Enthalpy at Partial Pressure**	**GAS2H2OHPP**	**1225.143**	**Btu/Lb**
39	**Water Vapor ASME Entropy at Partial Pressure**	**GAS2H2OSPP**	**2.1359245**	**Btu/Lb °R**
40	**Water Vapor Contribution to Specific Enthalpy**	**GAS2H2OH**	**59.17336**	**Btu/Lb**
41	**Water Vapor Contribution to Specific Entropy**	**GAS2H2OS**	**.1031634**	**Btu/Lb °R**
42	**Water Vapor Dew Point Temperature**	**GAS2DPT**	**106.7905**	**°F**

Dew point → temperature is only computable if the gas temperature is between -80°F and 705.47°F, otherwise GAS2DPT will return ”#N/A”.

12 Hint: To quickly enter the cell formulas in cells B30 to B35, enter the entire GAS2RT function in cell B30, then copy it to cells B31 to B35, and then change each cell to the correct function. Correct use of absolute references (e.g. $B$2) and relative references (e.g. B2) will ensure that copied formulas have the desired references.

To compute the water saturation vapor pressure, cell B44 contains the formula =GAS2SATP($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2SATP function uses the four arguments described on pages "EREXCEL-8" and "EREXCEL-9". The remaining results in cells B45 through B50 are computed in a similar manner using the same arguments and the function indicated in column A.[13]

These items are computable if the temperature is between -80°F and 705.47°F, otherwise they will return "#N/A". →

Wet-bulb temperature is computable if only air and perhaps water vapor are present and if the gas temperature is between -80°F and 200°F, otherwise GAS2WB will return "#N/A". →

	A		B	C
44	Water Saturation Vapor Pressure	GAS2SATP	161.0886	Psia
45	Degree of Water Saturation[14]	GAS2H2OSAT	-7.797244%	Percent
46	Relative Humidity (Water Vapor in Dry Gas)	GAS2RH	.7208939%	Percent
47	Humidity Ratio (Water Vapor in Dry Gas)	GAS2HMR	5.330768E-2	Lb/Lb
48	Specific Humidity (Water Vapor in Moist Gas)	GAS2HMS	4.829916E-2	Lb/Lb
49	Absolute Humidity (Water Vapor in Moist Gas)	GAS2HMA	2.367001E-3	Lb/Cuft
50	Thermodynamic Wet-Bulb Temperature	GAS2WB	#N/A	°F

To compute the Molecular Weight, cell B52 contains the formula =GAS2MW($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2MW function uses the four arguments described on pages "EREXCEL-8" and "EREXCEL-9". The remaining results in cells B53 through B56 are computed in a similar manner using the same arguments and the function indicated in column A.

	A		B	C
52	Molecular Weight	GAS2MW	29.47396	
53	Specific Gravity (Molecular Weight Ratio)[15]	GAS2SGMW	1.017536	[G]
54	Specific Gravity (Density Ratio) (Reference)[16]	GAS2SGREF	1.0187097	[G]
55	Specific Gravity (Density Ratio)[17]	GAS2SG	.6401903	[G]
56	Specific Heat [Cp][18] (Ideal Gas)	GAS2C	.2562904	Btu/Lb °F

13 Hint: To quickly enter the cell formulas in cells B44 to B50, enter the entire GAS2SATP function in cell B44, then copy it to cells B45 to B50, and then change each cell to the correct function. Correct use of absolute references (e.g. $B$2) and relative references (e.g. B2) will ensure that copied formulas have the desired references.

14 When saturation vapor pressure is greater than the total gas pressure as occurs with high temperature flue gas, and the relative humidity is greater than 0.00, the degree of saturation can be negative (See reference 7, page 1-15, equation 1.24).

15 The specific gravity value may be unrealistic if it is greater than 5.

16 The specific gravity value may be unrealistic if it is greater than 5.

17 The specific gravity value may be unrealistic if it is greater than 5.

18 If you need a faster method for computing the specific heat of flue gas, the GASTR2C function on page "EREXCEL-24" provides a fast and simple way to obtain an approximate value for the specific heat of flue gas at 14.696 psia.

To compute the ratio of specific heats, cell B58 contains the formula =GAS2CR($B$1, $B$2, $A$4:$A$13, $B$4:$B$13). The GAS2CR function uses the four arguments described on pages “EREXCEL-8” and “EREXCEL-9”. The remaining results in cells B59 through B70 are computed in a similar manner using the same arguments and the function indicated in column A.

	A		B	C
58	Ratio of Specific Heats (Ideal Gas)[19]	GAS2CR	1.357678	[Cp/Cv]
59	Temperature (Dry Ideal Gas + H_2O ASME)	GAS2TEMP	364.0922	°F
60	Specific Enthalpy (Dry Ideal Gas + H_2O ASME)	GAS2ENTH[20]	135.2667	Btu/Lb
61	Specific Entropy (Dry Ideal Gas + H_20 ASME)	GAS2ENTR[20]	.2211987	Btu/Lb °R
62	Compressibility Factor (Reference)[21]	GAS2Z0	0.9982604	[Z0]
63	Compressibility Factor[22]	GAS2Z1	0.9997867	[Z1]
64	Super Compressibility	GAS2SZ	1.000107	[Fpv]
65	Density (Reference)[23]	GAS2DR	7.798304E-2	Lb/Cuft
66	Density[24]	GAS2D	4.900708E-2	Lb/Cuft
67	Specific Volume (Reference)	GAS2RVOL	12.823300	Cuft/Lb
68	Specific Volume	GAS2VOL	20.405214	Cuft/Lb
69	Viscosity (Dry Ideal Gas)	GAS2U	1.572015E-05	Lb/Sec-ft
70	Viscosity (Dry Ideal Gas)	GAS2UC	2.339416E-02	Centipoise

Entering Gage Pressures

EndResult® functions require that all pressures to be entered as *absolute* pressures. If, however, you have a value in *gage* pressure (e.g. 1500 psig), simply add the atmospheric pressure (e.g. 14.696 psia) to the gage pressure as shown by the gas density calculation below:

=GAS2D(1500+14.696,300,$A$4:$A$13,$B$4:$B$13)

19 The specific heat ratio may be unrealistic if it is less than 0.1 or greater than 4.

20 Enthalpy and entropy calculations are based on a change in enthalpy or entropy from the zero enthalpy temperature, which can be modified as shown on page “EREXCEL-8”.

21 The compressibility factor (reference) may be unrealistic if it is greater than 1.24.

22 The compressibility factor may be unrealistic if it is greater than 1.24.

23 The density (reference) value may be unrealistic if it is greater than 100.

24 The density value may be unrealistic if it is greater than 100.

PCTBYVOL, PCTBYWT, GAS2PP, GAS2TSAT, and GAS2ZRA

Function	Computes an Individual Gas
PCTBYVOL..........	Percent by volume of the total gas mixture
PCTBYWT	Percent by weight of the total gas mixture
GAS2PP	Partial pressure
GAS2TSAT	Temperature of saturation
GAS2ZRA............	State at zero enthalpy, reference, and actual temp.

All five functions above require the same five arguments:

Arguments #1 to #4 The first four arguments are the same as those listed on pages "EREXCEL-8" and "EREXCEL-9".

Argument #5 The fifth argument must be one of the following gas names:

Acetylene, Air, Ammonia, Argon, Benzene, Carbon Dioxide, Carbon Monoxide, Ethane, Ethyl Alcohol, Ethylene, Hydrogen Gas, Hydrogen Sulfide, i-Butane, 1-Butene, i-Pentane, Methane, Methyl Alcohol, n-Butane, cis-2-Butene, n-Heptane, n-Hexane, n-Nonane, n-Octane, n-Pentane, 1-Pentene, Neopentane, Nitrogen, Atmospheric Nitrogen, Oxygen, Propane, Propylene, Sulfur Dioxide, Toluene, o-Xylene, m-Xylene, p-Xylene, Water Vapor.

For example, to compute the percent by volume of carbon dioxide of the total gas mixture, cell B74 below contains the formula =PCTBYVOL($B$1, $B$2, $A$4:$A$13, $B$4:$B$13, "Carbon Dioxide"). Similar formulas are used to compute the values in cells B74 through F78.

	A	B	C	D	E	F
72		% Volume	% Weight	Part Psia	Sat Temp (°F)	Z R A
73		=PCTBYVOL	=PCTBYWT	=GAS2PP	=GAS2TSAT	=GAS2ZRA
74	Carbon Dioxide	11.4940%	17.1626%	1.689	-164.54	____
75	Atmospheric Nitrogen	74.0720%	70.7724%	10.886	-324.35	____
76	Oxygen	6.4000%	6.9482%	0.941	-331.64	____
77	Sulfur Dioxide	0.1320%	0.2869%	0.019	-148.07	____
78	Water Vapor	7.9020%	4.8299%	1.161	106.79	ZR_

Under conditions of very low temperature and/or high pressure, one or more of the gas constituents may become liquid. If this happens for other than water vapor, your mixed gas results will not be valid (See warning on page "EREXCEL-9"). The GAS2ZRA function should be used if you are uncertain as to whether or not ALL of the constituents in the gas mixture will be a gas at the specified pressures and temperatures.

The GAS2ZRA function returns one or more of the following letters:

"Z" If the constituent is not a gas at zero enthalpy conditions
"R" If the constituent is not a gas at reference conditions
"A" If the constituent is not a gas at actual conditions

Computing Psychrometric Properties Using Relative Humidity

The worksheet below demonstrates how to compute the properties of atmospheric air with a given relative humidity.

		A	B	C	D	E	F
	100	Pressure		12	(from .9492356 to 15.472 Psia)		
	101	Dry Bulb Temperature		100	(from -80°F to 200°F)		
	102						
	103	Relative Humidity		80%	(from 0% to 100%)		
(applies to enthalpy and entropy, default is 32.018°F) →	104	Zero Enthalpy Temperature		40	(from -425°F to 4000°F)		
	105						
	106	Wet Bulb Temperature	GAS2WB	93.701501	°F		
	107	Reference Pressure	GAS2REFP	14.696	Psia		
	108	Reference Temperature	GAS2REFT	60	°F		
(Water Vapor in Dry Air) →	109	Humidity Ratio	GAS2HMR	4.197367E-2	Lb/Lb		
(Water Vapor in Moist Air) →	110	Specific Humidity	GAS2HMS	4.032289E-2	Lb/Lb		
(Water Vapor in Moist Air) →	111	Absolute Humidity	GAS2HMA	2.279395E-03	Lb/Cuft		
(Ideal Gas) →	112	Specific Heat [Cp] [25]	GAS2C	.24830705	Btu/Lb °F		
	113		% Volume	% Weight	Part Psia	Sat. Temp. (°F)	Z R A
	114		=PCTBYVOL	=PCTBYWT	=GAS2PP	=GAS2TSAT	=GAS2ZRA
	115	Air	93.6718%	95.9677%	11.241	-321.42	___
	116	Water Vapor	6.3282%	4.0323%	0.759	92.70	Z__

To compute the **Wet Bulb Temperature**[26], cell C106 contains the formula: =GAS2WB($C$100,$C$101,$A$103:$A$104,$C$103:$C$104).

=GAS2WB (*air_pressure, dry_bulb_temp, Ident_Range, Value_Range*)

The same arguments (as shown in the GAS2WB function above) can be used to perform the calculations shown in rows 107 through 116. The first two arguments must be the pressure and dry-bulb temperature of the atmospheric air and the last two arguments must be the Identifier and Value Ranges respectively in which you have specified the **Relative Humidity**. The only other item which you are allowed to specify in your Identifier and Value Ranges is the **Zero Enthalpy Temperature**. (A **Zero Enthalpy Temperature** of 32.018°F will be used if not otherwise specified.) For more detailed instructions on specifying the Identifier and Value Ranges, see pages "EREXCEL-8" and "EREXCEL-9".

25 If you need a faster method for computing the specific heat of air, the AIRT2C function on page "EREXCEL-24" provides a fast and simple way to obtain an approximate value for the specific heat of air at 14.696 psia.

26 For a chart of relative humidity versus dry bulb temperature and wet bulb temperature, see the ASHRAE Psychrometric Chart No. 1 (Normal Temperature)" and "ASHRAE Psychrometric Chart No. 2 (Low Temperature)" in the appendix of the Boiler Efficiency chapter.

Computing Psychrometric Properties Using Wet Bulb Temperature

The worksheet below demonstrates how to compute the properties of atmospheric air with a given wet bulb temperature.

		A	B	C	D	E	F
	130	Pressure		12	(from 1.274955 to 15.472 Psia)		
	131	Dry Bulb Temperature		110	(from -80°F to 200°F)		
	132						
	133	Wet Bulb Temperature		90	(from 56.7658°F to 110°F)		
(applies to enthalpy and entropy, default is 32.018°F) →	134	Zero Enthalpy Temperature		32.018	(from -425°F to 4000°F)		
	135						
	136	Relative Humidity	GAS2RH	48.65026%	Percent		
	137	Reference Pressure	GAS2REFP	14.696	Psia		
	138	Reference Temperature	GAS2REFT	60	°F		
(Water Vapor in Dry Air) →	139	Humidity Ratio	GAS2HMR	3.386498E-2	Lb/Lb		
(Water Vapor in Moist Air) →	140	Specific Humidity	GAS2HMS	3.278852E-2	Lb/Lb		
(Water Vapor in Moist Air) →	141	Absolute Humidity	GAS2HMA	1.828890E-3	Lb/Cuft		
(Ideal Gas) →	142	Specific Heat [Cp] [27]	GAS2C	.24681362	Btu/Lb °F		
	143		% Volume	% Weight	Part Psia	Sat. Temp. (°F)	Z R A
	144		=PCTBYVOL	=PCTBYWT	=GAS2PP	=GAS2TSAT	=GAS2ZRA
	145	Air	94.8311%	96.7211%	11.380	-321.26	____
	146	Water Vapor	5.1689%	3.2789%	0.620	86.26	Z__

To compute the **Relative Humidity**[28], cell C136 contains the formula: =GAS2RH($C$130,$C$131,$A$133:$A$134,$C$133:$C$134).

=GAS2RH (*air_pressure, dry_bulb_temp, Ident_Range, Value_Range*)

The same arguments (as shown in the GAS2RH function above) can be used to perform the calculations shown in cells rows 137 through 146. The first two arguments must be the pressure and dry-bulb temperature of the atmospheric air and the last two arguments must be the *Identifier* and *Value Ranges* in which you have specified the **Wet Bulb Temperature**[29]. The only other item which you are allowed to specify in you *Identifier* and *Value Ranges* is the **Zero Enthalpy Temperature**. (A **Zero Enthalpy Temperature** of 32.018°F will be used if not otherwise specified.) For more detailed instructions on specifying the *Identifier* and *Value Ranges*, see pages “EREXCEL-8” and ”EREXCEL-9”.

27 If you need a faster method for computing the specific heat of air, the AIRT2C function on page “EREXCEL-24” provides a fast and simple way to obtain an approximate value for the specific heat of air at 14.696 psia.

28 For a chart of relative humidity versus dry bulb temperature and wet bulb temperature, see the ”ASHRAE Psychrometric Chart No. 1 (Normal Temperature)” and “ASHRAE Psychrometric Chart No. 2 (Low Temperature)” in the appendix of the Boiler Efficiency chapter.

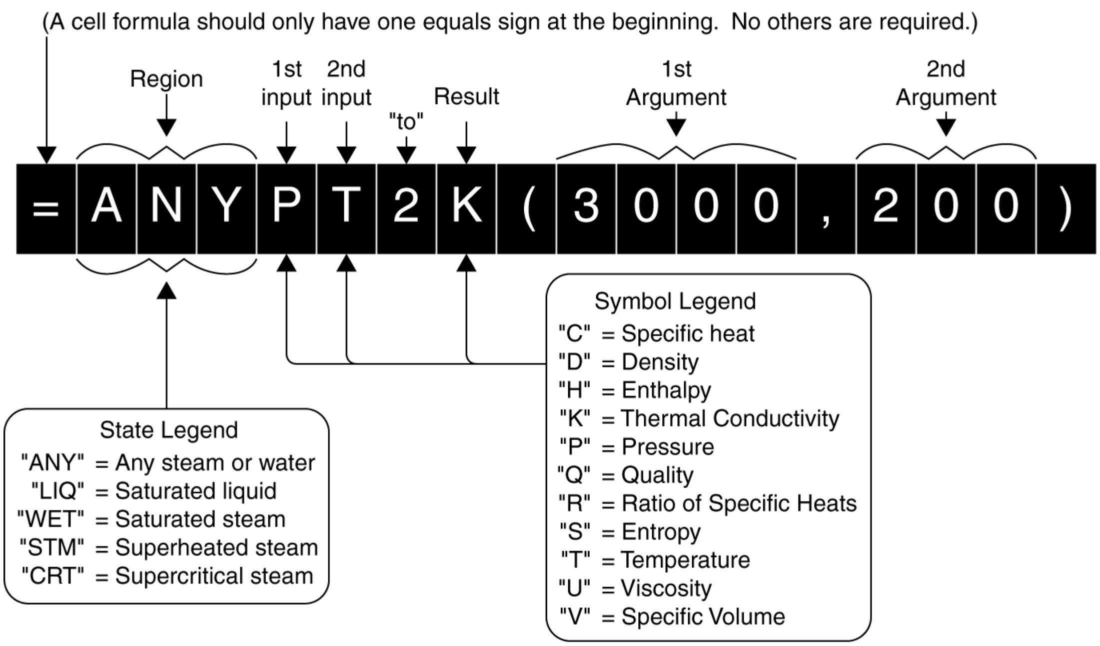
29- The wet-bulb temperature cannot be greater than the dry-bulb temperature. To obtain the *minimum* wet-bulb temperature, use the function =WETTEMP (*dry_bulb_temp, 0, air_pressure).* For example, if the dry-bulb temperature is 110°F and the air pressure is 14.696 psia, then the minimum wet-bulb temperature is 60.419°F.

Steam and Water Property Add-in

The steam and water property add-in includes functions for computing a variety of steam and water properties including: density, entropy, enthalpy, viscosity, pressure, temperature, quality, specific heat, ratio of specific heats, thermal conductivity, specific volume, saturation pressure, and saturation temperature.

EndResult®'s steam and water property calculations are based on formulations found in *ASME Steam Tables*[30] and are similar to those described in the “Steam Tables Properties” chapter. Each function has been tested to ensure that it produces the same values as the *ASME Steam Tables.*

All of the EndResult® steam and water property functions use a similar format to the example shown below:



From left to right, each function must have:

- 3 letters symbolizing the state
- 1 letter symbolizing the 1st input
- 1 letter symbolzing the 2nd input
- a number “2” symbolizing “TO”
- 1 letter symbolizing the result
- 2 arguments which you specify

Like bult-in Microsoft® Excel functions, each EndResult® function can be pasted into the spreadsheet by selecting **Paste Function…** from the **Formula** menu.

30 International Formulation Committee, *“The 1967 Formulation for Industrial Use”, ASME Steam Tables,* Fifth Edition, (New York: American Society of Mechanical Engineers, 1983), Appendix 1, pages 11-29.

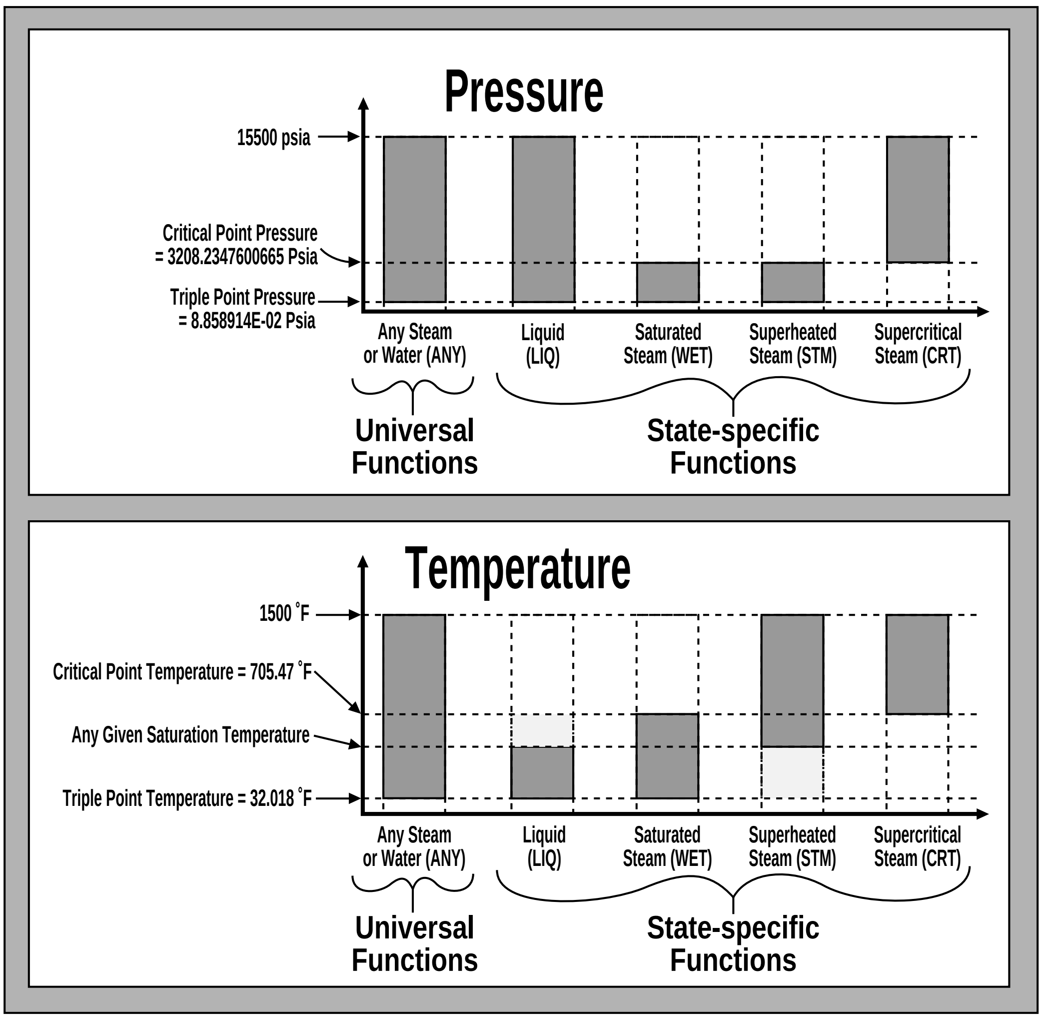
EndResult® functions require that all pressures be entered as *absolute* pressures. If, however, you have a value in *gage* pressure (e.g. 1500 psig), simply add the atmospheric pressure (e.g. 14.7 psia) to the gage pressure as shown by the liquid density calculation below:

=LIQPT2D(1500+14.7,300)

If you are interested in the properties of a particular steam or water state, select your function from the “State-specific” functions shown on page “EREXCEL-20”.

If you are unconcerned about the state of the steam and simply want to know the properties of any steam or water, select your function from the “Universal” functions shown on page “EREXCEL-19”.

The pressure and temperature minimums and maximums shown by the bar graphs below provide a visual description of the differences between the universal functions and the state-specific functions.



Steam and Water Property Universal Functions

The chart below describes the universal functions for calculating steam and water properties:

P_{3pt}	=Triple point pressure	=8.858914E-02 psia
T_{3pt}	=Triple point temperature	=32.018°F
P_{Cpt}	=Critical point pressure	=3208.2347600665 psia
T_{Cpt}	=Critical point temperature	=705.47°F
T_{Sat}	=Saturation temperature	=°F

Note: The ratio of specific heats is not available under the conditions described in the appendix of the Flow Measurement chapter on page “Flow-A4”.

Function & Inputs		Result	Units	Example
=ANYPT2…(*P*, *T*) *P*=Pressure (from P_{3pt} to 15500 psia) *T*=Temperature (from T_{3pt}°F to 1500°F)	…D …H …S …C …R …V …K …U	Density Enthalpy Entropy Specific Heat [Cp] Ratio of Specific Heats Specific Volume Thermal Conductivity Viscosity	Lb/Cuft Btu/Lb Btu/Lb °R Btu/Lb °F [Cp/Cv] Cuft/Lb Btu/Hr ft °F Lb/Sec-ft	To obtain the entropy of an H_2O substance at 6000 psia and 200 °F, enter =ANYPT2S (6000,200) and the result will be 0.287028 Btu/Lb °R.
=ANYPQ2… (*P, Q)* *P*=Pressure (from P_{3pt} to P_{Cpt} psia) *Q*=Quality (from 0% to 100%, enter as 0 to 1)	…D …H …S …C …R …V …T …K …U	Density Enthalpy Entropy Specific Heat [Cp] Ratio of Specific Heats Specific Volume Temperature Thermal Conductivity Viscosity	Lb/Cuft Btu/Lb Btu/Lb °R Btu/Lb °F [Cp/Cv] Cuft/Lb °F Btu/Hr ft °F Lb/Sec-ft	To obtain the thermal conductivity of an H_2O substance at 2600 Psia and 80% quality, enter =ANYPQ2K(2600,.8) and your answer will be 0.112809 Btu/Hr ft °F.
=ANYPH2…(*P*, *H*) *P*=Pressure (from P_{3pt} to 15500 psia) *H*=Enthalpy of liquid at T_{3pt} to enthalpy of superheated steam at 1500 °F in Btu/Lb	…D …S …Q …C …R …V …T …K …U	Density Entropy Quality Specific Heat [Cp] Ratio of Specific Heats Specific Volume Temperature Thermal Conductivity Viscosity	Lb/Cuft Btu/Lb °R Percent Btu/Lb °F [Cp/Cv] Cuft/Lb °F Btu/Hr ft °F Lb/Sec-ft	To obtain the density of an H_2O substance at 3000 psia and 500 Btu/Lb, enter =ANYPH2D(3000,500) and your result will be 49.5627 Lb/Cuft.
=ANYPS2…(*P*, *S*) *P*=Pressure (from P_{3pt} to 15500 psia) *S*=Entropy of liquid at T_{3pt} to entropy of superheated steam at 1500°F in Btu/Lb °R	…D …H …Q …C …R …V …T …K …U	Density Enthalpy Quality Specific Heat [Cp] Ratio of Specific Heats Specific Volume Temperature Thermal Conductivity Viscosity	Lb/Cuft Btu/Lb Percent Btu/Lb °F [Cp/Cv] Cuft/Lb °F Btu/Hr ft °F Lb/Sec-ft	To obtain the specific heat of an H2O substance at a pressure of 2600 Psia and an entropy of 1.2 Btu/Lb °R, enter =ANYPS2C(2600,1.2) and your answer will be 4.887736 Btu/Lb °F.

Steam and Water Property Region-Specific Functions

The chart below describes the region-specific functions for calculating steam and water properties:

T_{sat} = Saturation temperature = °F

P_{3pt} = Triple point pressure = 8.858914E-02 psia
P_{Cpt} = Critical point pressure = 3208.2347600665 psia

T_{3pt} = Triple point temp. = 32.018 °F
T_{Cpt} = Critical point temp. = 705.47 °F

	Function & Inputs		Result	Units	Example
Liquid (LIQ)	=LIQPT2…(*P*, *T*)	…D	Density	Lb/Cuft	To obtain the enthalpy
		…H	Enthalpy	Btu/Lb	of liquid at 2000 psia and
	P=Pressure	…S	Entropy	Btu/Lb°R	400°F, enter.
	(from P_{3pt} to 15500 psia)	…C	Specific Heat [Cp]	Btu/Lb°F	=LIQPTH(2000,400)
		…R	Ratio of Specific Heats	[Cp/Cv]	and your answer will be
	T=Temperature	…V	Specific Volume	Cuft/Lb	377.1851 Btu/Lb.
	(from T_{3pt}°F to T_{Sat} °F)	…K	Thermal Conductivity	Btu/Hr ft °F	
		…U	Viscosity	Lb/Sec-ft	
Saturated Steam (WET)	=WETPQ2… (*P*, *Q*)	…D	Density	Lb/Cuft	To obtain the entropy of
		…H	Enthalpy	Btu/Lb	saturated steam at 1800
	P=Pressure	…S	Entropy	Btu/Lb°R	psia and 45% quality,
	(from P_{3pt} to P_{Cpt} psia)	…T	Temperature	°F	enter
		…C	Specific Heat [Cp]	Btu/Lb °F	=WETPQ2S(1800,.45)
	Q=Quality	…R	Ratio of Specific Heats	[Cp/Cv]	and your answer will be
	(from 0% to 100%,	…V	Specific Volume	Cuft/Lb	1.051466 Btu/Lb °R.
	enter as 0 to 1)	…K	Thermal Conductivity	Btu/Hr ft °F	
		…U	Viscosity	Lb/Sec-ft	
Note: The ratio of specific heats is not available under the conditions described in the appendix of the Flow Measurement chapter on page “Flow-A4”.	=WETTQ2…(*T*, *Q*)	…D	Density	Lb/Cuft	To obtain the specific
		…H	Enthalpy	Btu/Lb	volume of saturated steam
	T=Temperature	…S	Entropy	Btu/Lb °R	at 200 °F and 70% quality,
	(from T_{3pt} °F to T_{Cpt} °F)	…P	Pressure	Psia	enter.
		…C	Specific Heat [Cp]	Btu/Lb °F	=WETTQ2V(200,.7) and
	Q= Quality	…R	Ratio of Specific Heats	[Cp/Cv]	the result will be 23.55216
	(from 0% to 100%,	…V	Specific Volume	Cuft/Lb	Cuft/Lb.
	enter as 0 to 1	…K	Thermal Conductivity	Btu/Hr ft °F	
		…U	Viscosity	Lb/Sec-ft	
Superheated Steam (STM)	=STMPT2…(*P*, *T*)	…D	Density	Lb/Cuft	To obtain the specific heat
		…H	Enthalpy	Btu/Lb	of superheated steam at
	P=Pressure	…S	Entropy	Btu/Lb °R	2000 psia and 950 °F,
	(from P_{3pt} to P_{Cpt} psia)	…C	Specific Heat [Cp]	Btu/Lb °F	enter
		…R	Ratio of Specific Heat	[Cp/Cv]	=STMPT2C(2000,950)
	T=Temperature	…V	Specific Volume	Cuft/Lb	and the result will be
	(from T_{Sat} °F to 1500 °F)	…K	Thermal Conductivity	Btu/Hr ft °F	0.652954 Btu/Lb °F.
		…U	Viscosity	Lb/Sec-ft	
Supercritical Steam (CRT)	=CRTPT2…(*P*, *T*)	…D	Density	Lb/Cuft	To obtain the thermal
		…H	Enthalpy	Btu/Lb	conductivity of super-
	P=Pressure	…S	Entropy	Btu/Lb °R	critical steam at 6000 psia
	(from P_{Cpt} psia to	…C	Specific Heat [Cp]	Btu/Lb °F	and 1200 °F, enter
	15500 psia)	…R	Ratio of Specific Heat	[Cp/Cv]	=CRTPT2K(6000,1200)
		…V	Specific Volume	Cuft/Lb	to get 0.073924
	T=Temperature	…K	Thermal Conductivity	Btu/Hr ft °F	Btu/Hr ft °F.
	(from T_{Cpt} to 1500 °F)	…U	Viscosity	Lb/Sec-ft	

Saturation Pressure & Temperature Functions

The chart below describes two functions which compute saturation pressure and temperature:

P_{3pt} = Triple point pressure = 8.858914E-02 psia
T_{3pt} = Triple point temperature = 32.018 °F
P_{Cpt} = Critical point pressure = 3208.2347600665 psia
T_{Cpt} = Critical point temperature = 705.47 °F
T_{Sat} = Saturation temperature = °F

Function	Result	Example
=T2P(*T*) *T*=Temperature (from T_{3pt} to T_{Cpt} °F)	Saturation Pressure	To obtain the saturation pressure of 79 °F steam, enter =T2P(79) and the answer will be 0.490491psia
=P2T(*P*) *P*=Pressure (from P_{3pt} to P_{Cpt} psia)	Saturation Temperature	To obtain the saturation temperature of 2000 psia steam, enter =P2T(2000) and your answer will be 635.8028 °F

Steam and Water Property Examples Worksheet

Part of the **STEAM.XLS** worksheet from your EndResult® **Examples** disk is shown below. The **STEAM.XLS** worksheet provides a working example of *all 79* steam and water property functions. You can experiment with each function by entering numbers into the **highlighted** unprotected user-input cells. The minimum and maximum value for each input is displayed just beneath each input cell. To compute steam density for example, cell E16 contains the formula =ANYPT2D($B$16,$B$20). The remaining results in column E are computed in a similar manner.

	A	B	C	D	E	F	G
16	Press. =	5000	Psia	Density =	5.8210023	Lb/Cuft	=ANYPT2D(P,T)
17	min:	0.08859		Enthalpy =	1529.1494	Btu/Lb	=ANYPT2H(P,T)
18	max:	15500		Entropy =	1.5060786	Btu/Lb °R	=ANYPT2S(P,T)
19				Viscosity =	2.529E-05	Lb/Sec-ft	=ANYPT2U(P,T)
20	Temp. =	1200	°F	Spec. Vol. =	0.1717917	Cuft/Lb	=ANYPT2V(P,T)
21	min:	32.018		Ther. Cond. =	0.0681597	Btu/Hr ft °F	=ANYPT2K(P,T)
22	max:	1500	Specific Heat [Cp] =		.7382281	Btu/Lb °F	=ANYPT2C(P,T)
23			Ratio of Specific Heats =		1.349910	[Cp/Cv]	=ANYPT2R(P,T)

Boiler Efficiency Add-in

The boiler efficiency add-in contains functions which perform many of the calculations necessary for computing boiler efficiency and gas turbine performance including:

- Moisture per Lb of Dry Ambient Air
- Specific Heat of Air
- Specific Heat of Flue Gas
- Combustion Calculations

The boiler efficiency add-in provides added flexibility by allowing you to either enter or compute many important quantities such as CO_2, O_2, H_2O, SO_2, Excess Air, dry and wet gas constituents, and air heater leakage.

Many of the calculations performed by the boiler efficiency add-in are based on equations found in *Steam Generating Units*[31] *Power Test Code (PTC 4.1)* and formulations found in *Steam/Its Generation and Use*[32]. Individuals who are familiar with *PTC 4.1* will find several of the example worksheets to be self-explanatory.

Inputs and results which are the same as those on the *PTC 4.1* short form test such as ”ENTHALPY OF WATER ENTERING" are preceded by a number followed by an equal’s sign (e.g. **17=Enthalpy of Water Entering**) in both the EndResult® example worksheets and the EndResult® Reference Manual.

The **COMBCYC.XLS, COGEN3.XLS, GASTURB.XLS, GASTURBI.XLS, HTWUNIT.XLS, PKGBLR.XLS,** and **UTILBLR.XLS** worksheets (provided on your EndResult® **Pre-defined Spreadsheet Solutions** disk) demonstrate how you can use the calculations for combustion, moisture per pound of air, specific heat of air, and specific heat of flue gas to compute boiler efficiency. The **COMBCYC.XLS, COGEN3.XLS, GASTURB.XLS, GASTURBI.XLS, HTWUNIT.XLS, PKGBLR.XLS** worksheets compute the combustion products of boilers and gas turbines *without* an air heater, and the **UTILBLR.XLS** worksheet computes the efficiency of a boiler *with* an air heater.

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31 *Steam Generating Units,* Power Test Code (PTC) 4.1, (New York: American Society of Mechanical Engineers, 1974).

32 Babcock & Wilcox. *Steam/Its Generation and Use,* 40th Edition (New York: Babcock & Wilcox Company, 1992), Section 6.

Moisture per Lb of Dry Ambient Air[33]

The **moisture per pound of dry ambient air** can be computed by the following four methods using either relative humidity (Methods 1 & 2) or wet-bulb temperature (Methods 3 & 4).

Method 1: The fast, approximate, and simplest method to compute moisture per pound of dry ambient air for a given relative humidity and *pressure* is to use the function H2ONAIR (*dry_bulb_temp, rel_humidity, air_pressure*). In the **MOISTURE.XLS** worksheet from your **Examples** disk (shown below), cell. B4 contains the formula =H2ONAIR($B$1, $B$2, $B$3).

Default is 14.696 psia if → pressure is omitted.

	A	B	C
1	Ambient air dry-bulb temperature	52	(from -80°F to 200°F)
2	Ambient air relative humidity	65%	(from 0% to 100%, 0 to 1)
3	Ambient air pressure	14.696	(from 2.25e-14 to 15.472 psia)
4	Moisture per Lb of Dry Ambient Air	5.3115E-03	Lb/Lb

Method 2: The slower but more rigorous method to compute moisture per pound of dry ambient air (i.e. "Humidity Ratio") for a given *relative humidity* and *pressure* is to use the GAS2HMR function as described on page "EREXCEL-15".

Method 3: The fast, approximate, and simplest method to compute moisture per pound of dry ambient air for a given wet-bulb temperature[34] and *pressure* is to use the function H2ONAIRW (*dry_bulb_temp, wet_bulb_temp, air_pressure*). In the **MOISTURE.XLS** worksheet from your **Examples** disk (shown below), cell B9 contains the formula =H2ONAIRW($B$6, $B$7, $B$8).

Default is 14.696 psia if pressure is omitted. →

	A	B	C
6	Ambient air dry-bulb temperature	65	(from -80°F to 200°F)
7	Ambient air wet-bulb temperature	58	(from 40.977°F to 65°F)
8	Ambient air pressure	14.696	(from 2.25e-14 to 15.472 psia)
9	Moisture per Lb of Dry Ambient Air	8.6698E-03	Lb/Lb

Method 4: The slower but more rigorous method to compute moisture per pound of dry ambient air (i.e. "Humidity Ratio") for a given *wet-bulb temperature*[34] and *pressure* is to use the GAS2HMR function as described on page "EREXCEL-16".

33 For a graph of moisture per pound of dry ambient air, see the "ASHRAE Psychrometric Chart No. 1 (Normal Temperature)" and "ASHRAE Psychrometric Chart No. 2 (Low Temperature)" in the appendix of the Boiler Efficiency chapter.

34 The wet-bulb temperature cannot be greater than the dry-bulb temperature. To obtain the *minimum* wet-bulb temperature, use the function =WETTEMP (*dry_bulb_temp, 0, air_pressure*). For example, if the dry-bulb temperature is 65°F and the air pressure is 14.696 psia, then the minimum wet-bulb temperature is 40.977°F.

Specific Heat of Air

The **specific heat of air** can be computed by the following two methods:

Method 1: The fast, approximate, and simplest method to compute specific heat of air *at 14.696 psia* is to use the function AIRT2C (*air_temperature*). In the **AIR-CP.XLS** worksheet from you **Examples** disk (shown below), cell B3 contains the formula =AIRT2C($B$1). The AIRT2C function reproduces the values given in *Steam Generating Units*[35] P*ower Test Code (PTC 4.1), Figure 3.* The AIRT2C function is convenient and provides adequate accuracy in many situations.

	A	B	C
1	Air temperature	400	(from 0°F to 1000°F)
2			
3	Specific Heat of Air (=AIRT2C)	0.24498	Btu/Lb °F

Method 2: The slow but more rigorous method to compute the specific heat of air at any pressure is to use the mixed gas GAS2C function as described on pages "EREXCEL-15" and "EREXCEL-16".

Specific Heat of Flue Gas

The **specific heat of flue gas** can be computed by the following two methods:

Method 1: The fast, approximate, and simplest method to compute specific heat of flue gas *at 14.696 psia* is to use the function GASTR2C (*gas_temp, carbon_to_hydrogen_ratio*). In the **GAS-CP.XLS** worksheet from you **Examples** disk (shown below), cell B4 contains the formula =GASTR2C($B$1,$B$2). The GASTR2C function reproduces the values given in *Steam Generating Units*[35] *Power Test Code (PTC 4.1), Figure 7.* The GASTR2C function is convenient and provides adequate accuracy in many situations.

	A	B	C
1	Flue gas temperature	500	(from 0°F to 1000°F)
2	Carbon to Hydrogen Ratio	20	(from 0 to 100)
3			
4	Specific Heat of Flue Gas (=GASTR2C)	0.249725	Btu/Lb °F

Method 2: The slower but more rigorous method to compute the specific heat of flue gas at *any pressure* is to use the mixed gas GAS2C function described on page "EREXCEL-12".

35 *Steam Generating Units*, *Power Test Code (PTC) 4.1*, (New York: American Society of Mechanical Engineers, 1974).

Combustion Calculations

The **COMBUST.XLS** worksheet from your **Examples** disk is shown below. Each molar combustion function requires 12 input arguments. The name of each argument appears in cells A1 to A17 and an example value for each argument appears in cells B1 to B17. ASME numbers (where applicable) appear in column A, and valid ranges for each input are listed in column C.

The Flue gas Measurement Selection pertains to the flue" gas measurements shown on rows 13 through 17 below. →

The Air Heater Selectioh determines whether each result described on pages 27 and 28 applies to conditions before the air heater, after the air heater, or to a boiler without an air heater (None). →

Argument #3 must be the Ultimate Analysis Range. In this example, the ultimate analysis is the shaded region to the right. →

Your fuel ultimate analysis ash is assumed by the add-in to be 100% minus the total of the specified ultimate analysis constituents. →

		A	B	C
	1	**Flue Gas Measurement Selection**	**Dry**	**(either Wet or Dry)**
	2	**Air Heater Selection**	**Before**	**(either Before, After, or None)**
	3	**43=Ultimate Analysis Carbon**	**49.8%**	**(from 0% to 100% by Weight)**
	4	**44=Ultimate Analysis Hydrogen**	**3.5%**	**(from 0% to 100% by Weight)**
	5	**45= Ultimate Analysis Oxygen**	**8.5%**	**(from 0% to 100% by Weight)**
	6	**46=Ultimate Analysis Nitrogen**	**.7%**	**(from 0% to 100% by Weight)**
	7	**47=Ultimate Analysis Sulfur**	**.6%**	**(from 0% to 100% by Weight)**
	8	**37=Ultimate Analysis Moisture**	**30.4%**	**(from 0% to 100% by Weight)**
	9	**22=Dry Refuse per Lb As Fired Fuel**	**0.0576**	**(from 0 to 1 Lb/Lb)**
	10	**23=Btu per Lb in Refuse (Wtd. Avg.)**	**48.7**	**(from 0 to 14500 Btu/Lb)**
	11	**Moisture per Lb of Dry Ambient Air**	**6.6598E-4**	**(from 0 to .081 Lb/Lb)**
	12	**36=Percent Excess Air**	**#N/A**	**(from -100% to 15000%, or #N/A)**[36]
Before air heater →	13	**32[37]=Carbon Dioxide in Flue Gas Before AH**	**#N/A**	**(from 0% to 20.9% by Vol, or #N/A)**[36]
Before air heater →	14	**33[37]=Oxygen in Flue Gas Before AH**	**3.5%**	**(from 0% to 20.9% by Vol, or #N/A)**[36]
Before air heater →	15	**34[37]=Carbon Monoxide in Flue Gas Before AH**	**.05%**	**(from 0% to 20.9% by Vol)**
After air heater →	16	**Diluted Carbon Dioxide after Air Heater**	**#N/A**	**(from 0% to 20.9% by Vol, or #N/A)**[36]
After air heater →	17	**Diluted Oxygen after Air Heater**	**4%**	**(from 0% to 20.9% by Vol, or #N/A)**[36]
	18			
	19	**24=Carbon burned per Lb As Fired Fuel**	**.4978065**	**Lb/Lb**

Notice that argument #3 is a range. →

Each combustion calculation add-in function requires the same arguments as the CARBURNED function in cell B19. To compute the Carbon burned per Lb as Fired Fuel, cell B19 contains the formula =CARBURNED($B$1, $B$2,**$B$3:$B$8**,$B$9,$B$10,$B$11,$B$12,$B$13,$B$14,$B$15,$B$16, $B$17).

36 See table on page "EREXCEL-26" for explanation.
37 ASME number applicable only if **Flue Gas Measurement Selection** is **Dry.**

Argument #1

As shown in the table below, set the **Flue Gas Measurement Selection** according to whether you want to enter each flue gas constituent's volumetric percent of a *wet* or *dry* flue gas sample.[38]

A "Wet" flue gas sample contains water vapor whereas a "dry" flue gas sample is water vapor free.

Arg No.	If Flue Gas Measurement Selection is "Dry", enter the following:	If the Flue Gas Measurement Selection is "Wet", enter the following:
13	32=Carbon Dioxide in ***Dry*** Flue gas Before AH	Carbon Dioxide in ***Wet*** Flue Gas before AH
14	33-Oxygen in ***Dry*** Flue Gas before air heater	Oxygen in ***Wet*** Flue Gas before air heater
15	34=Carbon Monoxide in ***Dry*** Flue Gas before AH	Carbon Monoxide in ***Wet*** Flue Gas before AH
16	Diluted ***Dry*** Gas CO_2 after air heater	Diluted ***Wet*** Gas CO_2 after air heater
17	Diluted ***Dry*** Gas Oxygen after air heater	Diluted ***Wet*** Gas Oxygen after air heater

Note: The higher the percent H_2 and H_2O in the fuel analysis, the more difference there will be between a wet-basis measurement and a dry-basis measurement. Generally, analyzers classified as insitu (in the gas stream) provide wet-basis (moisture not condensed out of sample) measurements. However, you will need to consult your analyzer manual to be sure.

Argument #2

Set the **Air Heater Selection** to **None** if:

(1) you want to compute flue gas properties for a boiler *without* an air heater.

(2) you want to compute flue gas properties for a boiler *with* an air heater and are *not interested* in the performance (i.e. leakage, etc.) of the air heater.

Set the **Air Heater Selection** to **Before** to compute flue gas properties *before* an existing air heater. Set the **Air Heater Selection** to **After** to compute flue gas properties *after* an existing air heater.

Argument #3

Argument #3 must be a range which includes *in exact order* the fuel ultimate analysis carbon, hydrogen, oxygen, nitrogen, sulfur, and moisture. The range in the example on page "EREXCEL-25"is from cell B3 to B8.

Arguments #7-#12

The table below displays the different ways in which you can enter measured percentages (shown as "__%") for arguments 12 to 17. Be sure to enter #N/A (rather than zero) for any *not measured* value. Specifying any combination of measured inputs not shown in the table below will cause the function to return an error message (i.e. "#N/A"). Be sure that any measurements taken for arguments 13 through 15 are taken before the air heater.

	Arg No.		If the Air Heater Selection is 'None'				If the Air Heater Selection is 'Before' or 'After'			
	12	36=Percent Excess Air	#N/A	#N/A	#N/A	__%	#N/A	#N/A	#N/A	#N/A
Before air heater →	13	32[39]=Carbon Dioxide in Flue Gas Before AH	__%	#N/A	__%	#N/A	__%	#N/A	__%	__%
Before air heater →	14	33[39]=Oxygen in Flue Gas Before AH	__%	__%	#N/A	#N/A	#N/A	__%	__%	__%
Before air heater →	15	34[39]=Carbon Monoxide in Flue Gas Before AH	__%	__%	__%	__%	__%	__%	__%	__%
After air heater →	16	Diluted Carbon Dioxide after air heater	#N/A	#N/A	#N/A	#N/A	__%	#N/A	__%	#N/A
After air heater →	17	Diluted Oxygen after air heater	#N/A	#N/A	#N/A	#N/A	#N/A	__%	#N/A	__%

An example of each of the 21 combustion calculation add-in functions appears in rows 19 through 48 of the spreadsheet on the following pages. Each function uses the inputs from rows 1 through 17 on page "EREXCEL-25".

38 For instructions on *"Converting a Wet-Basis Sample to a Dry-Basis Sample"* using the "Mixed Gas Thermo-Physical Properties" application see page "MixGas-12".

39 ASME number applicable only if **Flue Gas Measurement Selection** is **Dry.**

To compute the **Carbon burned per Lb As Fired Fuel**, cell B19 contains the formula =CARBURNED($B$1,$B$2,**$B$3:$B$8**,$B$9,$B$10,$B$11, $B$12,$B$13,$B$14,$B$15,$B$16,$B$17). The results in cells B20 through B28 are computed in a similar manner using the same arguments.[40]

	A		B	C
19	24=Carbon burned per Lb As Fired Fuel	CARBURNED	.4978065	Lb/Lb
20	Dry Air per Lb As Fired Fuel (AFF)	DRYAIR	7.8629727	Lb/Lb
21	36=Percent Excess Air	EXCESSAIR	19.3790%	Percent
22	25=Dry Gas per Lb As Fired Fuel (ASME)	DRYGAS	8.1818799	Lb/Lb
23	Wet Air per Lb As Fired Fuel (AFF)	WETAIR	7.8682093	Lb/Lb
24	Dry Gas Including Fly Ash (Wt. Basis)	BALDRY	8.1885761	Lb/Lb
25	Dry Gas Excluding Fly Ash (Wt. Basis)	MOLEDRY	8.1811761	Lb/Lb
26	Wet Flue Gas Including Fly Ash (Wt. Basis)	WETGAS	8.8106093	Lb/Lb
27	Wet Flue Gas Excluding Fly Ash (Wt. Basis)	MOLEWET	8.8032093	Lb/Lb
28	Air Heater Leakage (Actual)	LEAKAGE	2.57876%	% by Wt.

Notice the placement of the braces. →

Likewise, **Carbon Burned per Lb As Fired Fuel** (in cell B19) could also be computed by entering each argument directly as in: =CARBURNED("Dry","Before",{.498,.035,.085,.007,.006,.304},0.0576, 48.7,6.65979E-04,#N/A,#N/A,.035,.0005,#N/A,.04).

The dry flue gas constituents in cells B30 through B33 are computed by the ASME method which assumes that SO_2 condenses out with H_2O. To compute the carbon dioxide in dry flue gas by the ASME method, cell B30 contains the formula =DRYCO2($B$1,$B$2,**$B$3:$B$8,**$B$9,$B$10, $B$11,$B$12,$B$13,$B$14,$B$15,$B$16,$B$17). The remaining dry flue gas constituents in cells B31 through B33 are also computed by the ASME method using the same arguments.

	A		B	C
30	32=Carbon Dioxide (CO_2) in Dry Flue Gas (ASME)	DRYCO2	15.54476%	% by Vol
31	33=Oxygen (O_2) in Dry Flue Gas (ASME)	DRYO2	3.50000%	% by Vol
32	34=Carbon Monoxide in Dry Flue Gas (ASME)	DRYCO	0.05000%	% by Vol
33	35=Nitrogen (N_2) in Dry Flue Gas (ASME)	DRYN2ASME	80.90524%	% by Vol
34	Total		100.00000%	% by Vol

40 Hint: To quickly enter the cell formulas in cells B20 to B28, enter the entire CARBURNED function in cell B19, then copy it to cells B20 to B28, and then change each cell to the correct function. Correct use of absolute references (e.g. $B$2) and relative references (e.g. B2) will ensure that copied formulas have the desired references.

Notice the placement of the braces. →

Likewise, **Carbon Dioxide in Dry Flue Gas** (in cell B30 on the preceding page) could also be computed by entering each argument directly as in: =DRYCO2("Dry","Before",{.498,.035,.085,.007,.006,.304},0.0576,48.7, 6.65979E-04,#N/A,#N/A,.035,.0005,#N/A,.04).

The dry flue gas constituents in cells B36 through B40 are computed by the "Total Gas" method which assumes that SO_2 is not condensed out with H_2O. To compute the carbon dioxide in dry flue gas by the "Total Gas" method, cell B36 contains the formula =DRYCO2($B$1,$B$2,**$B$3:$B$8**,$B$9,$B$10,$B$11,$B$12,$B$13,$B$14,$B$15,$B$16,$B$17). The remaining dry flue gas constitutents in cells B37 through B40 are also computed by the "Total Gas" method using the same arguments.[41]

Note: The add-in assumes that 100% of the sulfur is burned to yield only SO_2. →

	A		B	C
36	32=Carbon Dioxide (CO_2) in Dry Flue Gas	DRYCO2	15.54476%	% by Vol
37	33=Oxygen (O_2) in Dry Flue Gas	DRYO2	3.50000%	% by Vol
38	34=Carbon Monoxide in Dry Flue Gas	DRYCO	0.05000%	% by Vol
39	35=Nitrogen (N_2) in Dry Flue Gas	DRYN2	80.83483%	% by Vol
40	Sulfur Dioxide (SO_2) in Dry Flue Gas	DRYSO2	0.07041%	% by Vol
41	Total		100.00000%	% by Vol

To compute the carbon dioxide in wet flue gas, cell B43 contains the formula =WETCO2($B$1,$B$2,**$B$3:$B$8**,$B$9,$B$10,$B$11,$B$12, $B$13,$B$14,$B$15,$B$16,$B$17). The remaining wet flue gas constituents in cells B44 through B48 are computed in a similar manner using the same arguments.

(See note above) →

	A		B	C
43	Carbon Dioxide (CO_2) in Wet Flue Gas	WETCO2	13.75737%	% by Vol
44	Oxygen (O_2) in Wet Flue Gas	WETO2	3.09756%	% by Vol
45	Carbon Monoxide (CO) in Wet Flue Gas	WETCO	0.04425%	% by Vol
46	Nitrogen (N_2) in Wet Flue Gas	WETN2	71.54016%	% by Vol
47	Water Vapor (H_2O) in Wet Flue Gas	WETH2O	11.49835%	% by Vol
48	Sulfur Dioxide (SO_2) in Wet Flue Gas	WETSO2	.06231%	% by Vol
49	Total		100.00000%	% by Vol

Likewise, **Carbon Dioxide in Wet Flue Gas** (in cell B43) could also be computed by entering each argument directly as in: =WETCO2,("Dry","Before",{.498,.035, .085,.007,.006,.304},0.0576,48.7,6.65979E-04,#N/A,#N/A,.035,.0005,#N/A,.04).

41 Hint: To quickly enter the cell formulas in cells B37 to B40, enter the entire DRYCO2 function in cell B36, then copy it to cells B37 to B40, and then change each cell to the correct function. Correct use of absolute references (e.g. $B$2) and relative references (e.g. B2) will ensure that copied formulas have the desired references.

Heat Loss Due to Radiation

The **RADLOSS** and **RADLOSS2** functions described in this section provide two separate methods for computing ABMA radiation loss in percent as fired fuel (%AFF) for a boiler. 69=**Heat Loss Due To Radiation** is the percent of heat energy in the fuel lost to surface radiation and convection off the outside skin of the boiler. **Heat Loss Due to Radiation** increases as: (1) the **Number of Water Walls** (i.e. water-cooled furnace walls) decreases, (2) the **Air Velocity Around Boiler** increases, and (3) the **Air to Boiler Temperature Delta** (i.e. difference) increases.

The **RADLOSS.XLS** worksheet from your **Examples** disk is shown below. The inputs appear in the first 12 rows, and the result appears in row 14. Cell B14 contains the formula RADLOSS($B$1,$B$2,$B$3,$B$4,$B$5,$B$6, $B$7,$B$8,$B$9,$B$10,$B$11,$B$12). ASME numbers (where applicable) appear in column A, and valid ranges for each input are listed in column C.

For *standard* radiation loss enter an air velocity around boiler of 100 FPM and an air to boiler temperature delta of 50°F.

If the boiler does not have a reheater, enter #N/A for the last three arguments (i.e. cells B10 to B12).

	A	B	C
1	Boiler Capacity	4800000	(from 500 to 10E+06 Lb/Hr)
2	Number of Water Walls	4	(from 0 to 4)
3	Drum Blowdown Water Flow	46000	(from 0 to 10E+06 Lb/Hr)
4	Air Velocity Around Boiler	100	(from 0 to 1800 FPM)
5	Air to Boiler Temperature Delta	50	(from 0°F to 2000°F)
6	15=Enthalpy of Saturated Liquid	733.5924	(from 1E-7 to 906.96 Btu/Lb)
7	16=Enthalpy of Superheated Steam	1460.3950	(from 715.86 to 1586 Btu/Lb)
8	17=Enthalpy of Water Entering	442.5746	(from 1E-7 to 906.96 Btu/Lb)
9	26=Actual Water Evaporated	4640000	(from 500 to 10E+06 Lb/Hr)
10	18=Enthalpy of Steam at R.H. Inlet	1299.7101	(from 715.86 to 1586 Btu/Lb, or #N/A)
11	19=Enthalpy of Steam at R.H. Outlet	1520.2431	(from 715.86 to 1586 Btu/Lb, or #N/A)
12	27=Reheat Steam Flow	4200000	(from 500 to 10E+06 Lb/Hr, or #N/A)
13			
14	69=Heat Loss Due to Radiation RADLOSS	0.172002%	% AFF of gross heat input

You can also enter the formula values directly. For example, the radiation loss shown in cell B14 above could also be calculated by entering the formula =RADLOSS(4800000,4,46000,100,50,733.5924,1460.3950, 442.5746,4640000,1299.7101,1520.2431,4200000).

Although **RADLOSS** is not compensated for superheat or reheat spray flow, because of the nature of radiation loss on large boilers, the error is considered negligible. However, if you prefer you can calculate the maximum boiler heat output and the actual heat output and use **RADLOSS2.**

The **PKGBLR.XLS** and **UTILBLR.XLS** worksheets (provided on your EndResult® **Pre-defined Spreadsheet Solutions** disk) demonstrate how the radiation loss (RADLOSS) add-in function can be combined with other functions to compute boiler efficiency. The **PKGBLR.XLS** worksheet computes the efficiency of a boiler *without* a reheater, and the **UTILBLR.XLS** worksheet provides a demonstration of an efficiency calculation for a boiler *with* a reheater.

The **RADLOSS2.XLS** worksheet from your EndResult® **Examples** disk is shown below. The inputs appear in the first 5 rows, and the result appears in row 7. Cell B7 contains the formula =RADLOSS2($B$1,$B$2,$B$3,$B$4,$B$5). ASME numbers (where applicable) appear in column A, and valid ranges for each input are listed in column C.

The Actual Btu cannot be greater than the rated Btu.

For standard radiation loss enter an air velocity around boiler for 100 FPM and an Air to Boiler Temperature Delta of 50°F.

	A	B	C
1	**Actual Btu**	**200**	**(from 1 to 10E+06 Mbtu/Hr)**
2	**Rated Btu**	**400**	**(from 1 to 10E+06 Mbtu/Hr)**
3	**Number of Water Walls**	**4**	**(from 0 to 4)**
4	**Air Velocity Around Boiler**	**100**	**(from 0 to 1800 Fpm)**
5	**Air to Boiler Temperature Delta**	**50**	**(from 0°F to 2000°F)**
6			
7	**69=Heat Loss Due to Radiation RADLOSS2**	**0.61718%**	**% AFF of gross heat input**

Likewise, **Heat Loss Due to Radiation** (in cell B7) can also be computed by entering each argument directly as in: =RADLOSS2(200,400,4,100,50).

The **HTWUNIT.XLS** worksheet (provided on your EndResult® **Pre-defined Spreadsheet Solutions** disk) demonstrates how the radiation loss (RADLOSS2) add-in function can be combined with other functions to compute boiler efficiency.

Curve Fitting Add-in

The following table summarizes the general types of models which can be computed using the curve fitting add-in functions and the minimum number of points for each model.

Where n = the number of independent variables (from 1 to 9):

General Model Types

Model Type	Minimum Number of Points	General Equation y=Dependent Variable x_1,x_2,x_3,etc.=Each Independent Variable A_1,A_2,A_3,etc.=Each Coefficient
Polynomial	depends(*)	$y = A_1(x_1)^n + A_2(x_2)^n + ... + const$
Power	n + 1	$y = (x_1)^{A1} * (x_2)^{A2} * ... * (x_n)^{An} * A_{n+1}$
Logarithmic	n + 1	$y = A_1LN(x_1) + A_2LN(x_2) + ... + A_nLN(x_n) + A_{n+1}$
Inverse	n + 1	$y = A_1/x_1 + A_2/x_2 + ... + A_n/x_n + A_{n+1}$
Exponential	n + 1	$y = e\text{^}(A_1x_1) * e\text{^}(A_2x_2) * ... * e\text{^}(A_nx_n) * A_{n+1}$
Square root	n + 1	$y = A_1(x_1)^{(1/2)} + A_2(x_2)^{(1/2)} + ... + A_n(x_n)^{(1/2)} + A_{n+1}$

(*) See "Modeling Using Polynomials" on page 36.

If you want to develop a square model or a square root model using *only* two points, see the SQRXYXY and SQRTXYXY functions described on page 47.

Unless you expect that your data points are distributed in such a way that they can be modeled using a "Power", "Logarithmic", "Inverse", "Exponential", or "Square Root" equation, you will probably obtain the greatest accuracy by using the "Polynomial" model.

The curve fitting add-in functions use the "least squares" method to compute each mathematical model. Each model is a *function*, which means that for one or more independent variables, there is one and only one dependent variable (i.e. result). The following table demonstrates how a *point* is defined by the number of independent variables:

Number of Independent Variables	Required format for each point y=Dependent Variable x_1,x_2,x_3,etc.=Each Independent Variable
1	(x_1,y)
2	(x_1,x_2,y)
3	(x_1,x_2,x_3,y)
4	(x_1,x_2,x_3,x_4,y)
5	(x_1,x_2,x_3,x_4,x_5,y)
6	$(x_1,x_2,x_3,x_4,x_5,x_6,y)$
7	$(x_1,x_2,x_3,x_4,x_5,x_6,x_7,y)$
8	$(x_1,x_2,x_3,x_4,x_5,x_6,x_7,x_8,y)$
9	$(x_1,x_2,x_3,x_4,x_5,x_6,x_7,x_8,x_9,y)$

Curve Fitting Add-in Functions

The chart below summarizes the curve fitting add-in functions.

Since there is no reason to compare your original points to a *derivative* of your model, the FITR2, FITAVGDEV, and FITMAXDEV functions will return "#N/A" if you have → any "d/" instructions in your model *type$.*

We recommend that you allocate a *named* cell in your worksheet to store the value of *each* independent variable. You can assign a name to a cell by selecting Insert Name Define… from the Microsoft® Excel (Versions 3, 4, or 7) menus or Formula Define Name… from the Microsoft® Excel (Version 5) menu. For example, the independent variable X was defined as cell $E$2 shown on page 33.

=FITEQ (*point_range, type$)*

=FITVAL *(point_range, type$, IV$)*

=FITR2 *(point_range, type$)*

=FITAVGDEV (point_range, type$)

=FITMAXDEV *(point_range, type$)*

=EQFRAGMENT *(point_range, type$, fragment)*

type$ = the model type (enclosed in quotes) must be selected from the following list:
"sqrt" for a square root model,
"log" for a logarithmic model,
"inv" for an inverse model,
"power" for a power model,
"exp" for an exponential model, or
"poly *n*" for an *nth* degree polynomial where *n* is from 1 to 9.

See "Taking the *nth* Derivative of a Model" on page 36 for additional options which you can include in your *type$.*

point_range = a range containing from 2 to 150 data points. As shown in the example on the following page, the first row of the *point_range* should contain the name of each independent variable and the name of the dependent variable. You can specify from 1 to 9 independent variables. You should provide a separate column for each *independent* variable. However, the rightmost column should always contain the *dependent* variable. The data points in the example worksheet on the following page contain only one independent variable "X" and the dependent variable "Y".

IV$ = the value of each independent variable enclosed in quotes (e.g. "press=6.31, temp=7.31"). Each independent variable name must appear in the top row of the *point_range* in all but the rightmost column.

fragment = the *nth* part of an equation. The beginning of the equation is always fragment 1.

FITEQ returns the equation of the *type$* model which fits the data in the spreadsheet. FITEQ uses the independent and dependent variable names which you specified in the first row of your *point_range*. Cell C23 on the following page contains the formula =FITEQ($A$1:$B$19,"Poly2") which returns the equation of the 2nd-order polynomial which fits the data points in the *point_range*. To obtain a "live" function: (1) Select **Edit Copy…**, (2) Move the pointer to a different cell and

FITEQ (cont.)
select **Edit Paste Special…,** (3) Click the **Values** option button and then click OK, and (4) Insert an equals sign ("=") at the beginning of the equation.

FITVAL returns the value of the *type$* model for the given values of the independent variables. Cell E35 on page 34 contains the formula FITVAL($A$1:$B$19,"exp","x=72") which returns the value of the exponential model at x = 72. The =FITVAL function should only be used for "spot checking". Once your model is finished, be sure to use the FITEQ function to convert the model to a "live" equation.

FITR2 returns the correlation coefficient (r^2) of the *type$* model. The value of r^2 is from 0 to 1, and the closer r^2 is to 1, the better the fit. A correlation coefficient of 1 is a perfect fit. Cell D36 on page 34 contains the formula =FITR2($A$1:$B$19,"sqrt") which returns the correlation coefficient of the square root curve which fits the data points in the *point_range*.

FITAVGDEV returns the average absolute deviation of the *type$* model from the specified points. The average absolute deviation is the average gap (or average error) between the model and the entered points. If the computed model passes directly through *all* of the entered points, the average absolute deviation will be *zero*. Cell C37 on page 34 contains the formula =FITAVGDEV($A$1:$B$19,"log") which returns the average absolute deviation of the logarithmic equation from the data points in the *point_range.*

FITMAXDEV returns the maximum absolute deviation (i.e. maximum error) of the *type$* model from specified points. The maximum absolute deviation is the largest gap (or greatest error) between the model and any of the entered points. If the computed model passes directly through *all* of the entered points, the maximum absolute deviation will be *zero*. Cell B38 on page 34 contains the formula =FITMAXDEV($A$1:$B$19,"power") which returns the maximum absolute deviation of the power equation from the data points in the *point_range.*

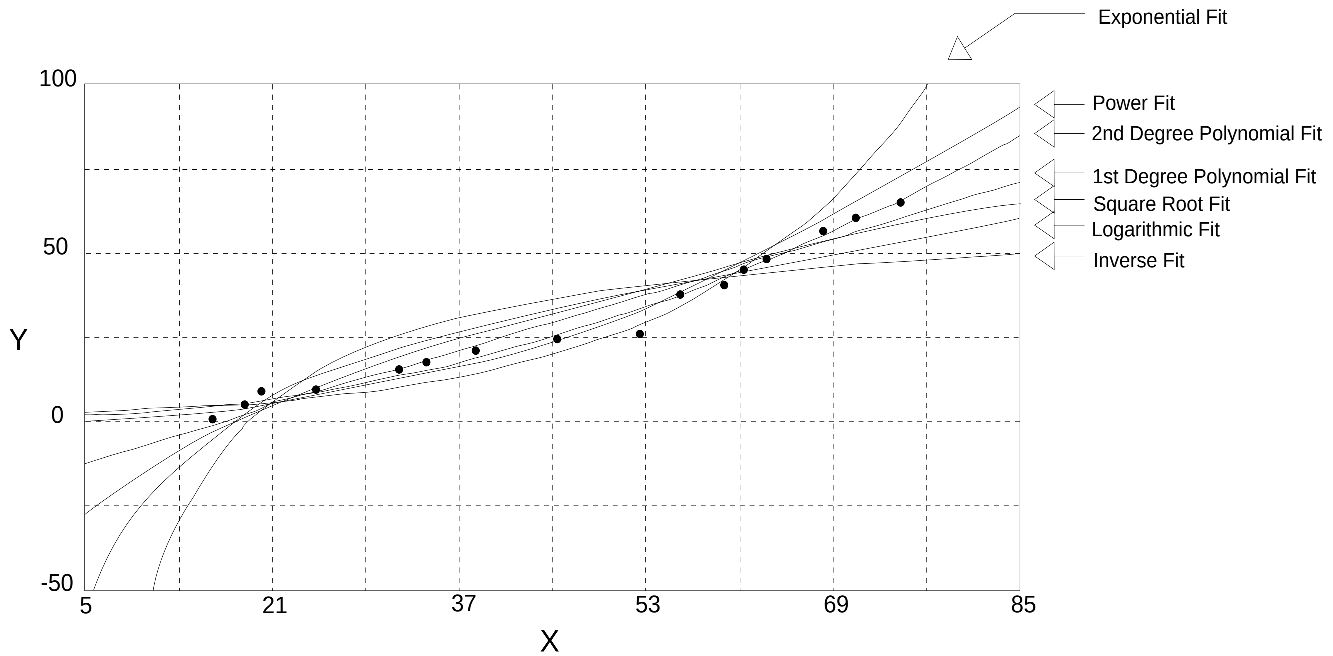
EQFRAGMENT is discussed in the section entitled "Computing Equations Longer than 255 Characters" on page 41.

Part of the **FIT.XLS** worksheet from your EndResult® **Examples** disk is shown below:

Note: To sort your points in either ascending or descending order, select the entire table of points and use the Data Sort… command. →

	A	B	C	D	E	F
1	X	Y				
2	15.93	0.850		X=	72	
3	18.79	4.410				
4	19.99	8.710				
5	24.70	9.31				
6	31.86	14.62				
7	34.12	17.32				
8	34.35	17.58				
9	38.40	21.08				
10	45.36	23.94				
11	52.44	25.87				
12	55.83	37.11				
13	59.64	40.13				
14	61.31	45.89				
15	63.24	49.66				
16	68.08	56.89				
17	68.19	57.69				
18	70.88	60.49				
19	74.73	65.05				
20						
21	Model Type		Equation returned by FITEQ			
22	Polynomial (1st)	Y=	-17.7142520110828+1.04489704024574*X			
23	Polynomial (2nd)	Y=	+1.48114956107175+0.00676722952131612*X+0.0115013843515338*X^2			
24	Exponential	Y=	+2.00069041435995*EXP(0.0507535135189556*X)			
25	Square Root	Y=	-56.7239732569892+13.164884868393*X^0.5			
26	Logarithmic	Y=	-116.206639541582+39.3830687552381*LN(X)			
27	Power	Y=	+0.00825314588685043*X^2.10208656290306			
28	Inverse	Y=	+63.2729139063545-1195.43012344389/X			

The data points and equations from the previous page are shown on the graph below:



	A	B	C	D	E	F
29						
30	Model	Maximum	Average	Correlation	Value at	
31	Type	Deviation	Deviation	Coefficient	X=72	
32		=FITMAXDEV	=FITAVGDEV	=FITR2	=FITVAL	
33	Polynomial (1st)	11.2101	3.2109	0.959092	57.5183	
34	Polynomial (2nd)	7.5943	2.0504	0.984010	61.5916	
35	Exponential	23.7425	5.2464	0.923115	77.3040	
36	Square Root	12.7402	4.7785	0.925357	54.9838	
37	Logarithmic	13.8673	6.3737	0.875620	52.2216	
38	Power	8.1316	2.9507	0.976033	66.2054	
39	Inverse	17.7737	9.4447	0.739488	46.6697	

Modeling Using Polynomials

The following table lists the *minimum* number of points which you must enter to compute polynomial equations of various degrees with various numbers of independent variables.

Minimum Number of Points		Polynomial Degree									Maximum Polynomial Degree
		1	2	3	4	5	6	7	8	9	
Number of Independent Variables	1	2	3	4	5	6	7	8	9	10	9
	2	3	6	10	15	2	28	36	45	–	8
	3	4	10	20	35	–	–	–	–	–	4
	4	5	15	35	–	–	–	–	–	--	3
	5	6	21	--	–	–	–	–	–	--	2
	6	7	28	--	–	–	–	–	–	--	2
	7	8	36	--	–	–	–	–	–	--	2
	8	9	45	--	–	–	–	–	–	--	2
	9	10	–	--	–	–	–	–	–	--	1

Additionally, the rightmost column of the table above shows the maximum degree polynomial which can be computed by the curve fitting add-in functions due to the number of independent variables.

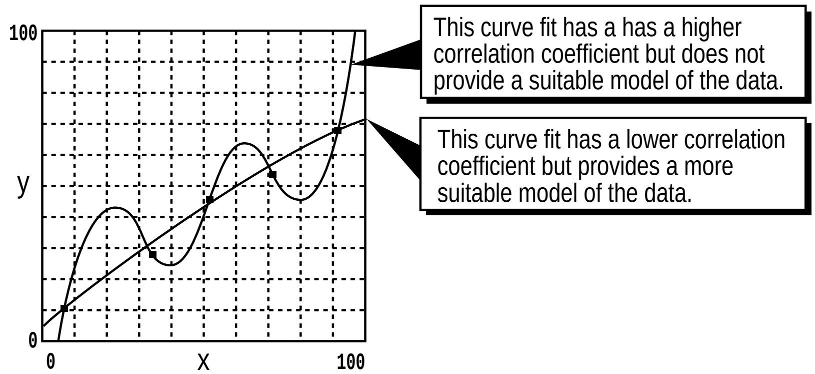
The following table contains several commonly used polynomial models which can be computed using the curve fitting add-in functions.

Form of Polynomial	Model Type$	Number of Independent Variables (1 to 9)	Minimum Number of Points	Polynomial Equations y=Dependent Variable $x_1 x_2 x_3$,etc.=Each Independent Variable A,B,C,etc.=Each Coefficient	(*) Polynomial Degree (1 to 9)
Linear	"Poly1"	1	2	$y = Ax_1 + B$	1
Parabolic	"Poly2"	1	3	$y = A(x_1)^2 + B(x_1) + C$	2
Cubic	"Poly3"	1	4	$y = A(x_1)^3 + B(x_1)^2 + C(x_1) + D$	3
Quartic	"Poly4"	1	5	$y = A(x_1)^4 + B(x_1)^3 + C(x_1)^2 + D(x_1) + E$	4
Plane	"Poly1"	2	3	$y = A(x_1) + B(x_2) + C$	1
Paraboloid(*) (* eliptic or hyperbolic)	"Poly2"	2	6	$y = A(x_1)^2 + B(x_1) + C(x_2)^2 + D(x_2) + E(x_1)(x_2) + F$	2
Large Polynomial	"Poly2"	3	10	$y = A(x_1)^2 + B(x_2)^2 + C(x_3)^2 + D(x_1) + E(x_2) + F(x_3) + G(x_1)(x_2) + H(x_1)(x_3) + I(x_2)(x_3) + J$	2
First Degree	NA	n	n + 1	$y = A_1 x_1 + A_2 x_2 + \ldots + A_n x_n + A_{n+1}$	NA

(*) In the polynomial equations above, the highest power of an independent variable (e.g. x_1, x_2, x_3, etc.) in the equation is the "Polynomial Degree" shown in the rightmost column.

You should probably experiment with many different degrees of polynomial fits, before deciding which polynomial model is the best. Typically, there is an optimum degree of fit for the polynomial. Computing for degrees which are higher or lower than the optimum degree may decrease the desirability or accuracy of the fit.

The example graph below illustrates how a curve fit with a lower degree (and a lower correlation coefficient) may be a more suitable model for the data than a curve fit with a higher degree (and a higher correlation coefficient).



Taking the *nth* Derivative of a Model

The table below demonstrates how you can take the *nth* derivative of a model by adding one or more “d/” instructions to your model *type$ (type$* is discussed on page 32). If you have multiple independent variables in your model, then you can obtain the *nth* partial derivative with respect to one or more independent variable(s).

Example Formulas	Examples Explained
=FITEQ($A$1:$B$19,"Poly4 d/X^2”)	Computes the equation of the 2nd derivative with respect to X of the 4th degree polynomial.
=FITVAL($A$1:$B$19,"Poly5 d/A^2 d/B","A=3,B-5")	Computes the value of the 2nd derivative with respect to A and the 1st derivative with respect to B of the 5th degree polynomial at the value A=3 and B=5.
=FITEQ($A$1:$B$19, “Poly4 d/X d/X”)	Computes the equation of the 2nd derivative with respect to X of the 4th degree polynomial.

Since there is no reason to compare your original points to a *derivative* of your model, the FITR2, FITAVGDEV, and FITMAXDEV functions will return “#N/A” if you have any “d/” instructions in your model *type$*.

Determining the Accuracy of the Fit

Each model computed by the curve fitting add-in functions is a “best fitting” curve which passes directly through or as close to the entered points as possible with a smooth transition between the points. As you might expect, if your data is “scattered,” it may be difficult to find a curve which closely fits all of your points. The maximum (FITMAXDEV) and average (FITAVGDEV) deviations, as well as the correlation coefficient (FITR2), provide a measure of accuracy of each type of fit to the points. The best fitting model has the *smallest* maximum and average deviations and the *largest* correlation coefficient. However, since even curves with a good fit can include unexpected or undesirable changes in direction, you should always *graph* your data along with each computed model to determine which curve fit is most appropriate, applicable, and realistic for your particular situation.

Developing Accurate Models

You want to have as many data points as possible when developing an accurate model. You should experiment with several different types of models to determine which model fits your data most appropriately. The best way to do this kind of experimentation is by plotting each model on a graph. For example, if you are using a mathematical model for forecasting, (i.e., to predict values beyond the points which you currently know), then you should test how different types of models react in the forecasted range by plotting each one on a graph. The example graph on page 34 demonstrates how your computed results depend greatly on which type of model you choose.

Improving Accuracy by Modeling Small Regions Separately

If your data points are scattered, you may *not* be able to obtain a single equation which will fit *all* of the points with the desired accuracy. In this case, greater accuracy can be obtained by dividing your points into two or more groups and then modeling each group separately. After you have divided your points, you can make the transition between adjacent models smoother by forcing the models to overlap. You can overlap adjacent models by putting points on *both* sides of the model border into each model's *point_range*. (The *point_range* is discussed on page 32).

You can use the following procedure to determine when and where you should use multiple models:

Step 1: Select a model type (e.g., "Poly3", "Poly4", etc.) which will provide the best fit for *all* of the data points.

Step 2: Use this model to compute the dependent variable for each of your known points.

Step 3: Compute the difference between the actual and computed values of the dependent variable for each of your known points.

Step 4: If the model deviates significantly from some of the points, you may need to take these points out of the main group and model them separately.

Performing Linear Interpolation and Extrapolation

To perform linear interpolation or extrapolation, simply use the FITEQ(*point_range*, "Poly1") function (on page 32) to solve for a first degree polynomial. After using the FITEQ function to compute the equation of the line, you can compute points: (1) *between* your known points (i.e., "interpolation"), or (2) *beyond* your known points (i.e., "extrapolation").

If you want to perform interpolation or extrapolation using *only* two points, see the INTERP and EXTRAP functions described on page 46.

Computing Equations Longer than 255 Characters

The longest equation which can be returned by the FITEQ function is 255 characters. To obtain an equation which is longer than 255 characters, you must use multiple EQFRAGMENT functions. If the equation is too long for FITEQ to display, it will return an "EQFRAGMENT" line like that shown below:

Notice that this "EQFRAGMEMT" line indicates that the equation is composed of *three* fragments. →

	A	B	C	D	E	F
51		**=EQFRAGMENT(point_range,"Poly6:,1)+…+EQFRAGMENT(point_range,"Poly6,3)**				

To return the entire function, you must enter each EQFRAGMENT function into a separate cell as shown in cells B53 through B55 below.

Remember to replace "point_range" with the worksheet range → where your points are located. For → example, the point range for the points → on page 33 is $A$1:$B$19.

	A	B	C	D	E	F
53		**=EQFRAGMENT(point_range,"Poly",1)**				
54		**=EQFRAGMENT(point_range,"Poly6",2)**				
55		**=EQFRAGMENT(point_range,"Poly6",3)**				

To convert each EQFRAGMENT function to a "live" equation:

(1) Select the cells containing the EQFRAGMENT functions,

(2) Select **Edit Copy…** from the Excel menu,

(3) Move the pointer to an empty area in the worksheet and **Edit Paste Special…,** and

(4) Click the **Values** option button and then click OK.

The long equation to the → right was computed by fitting a 6th–degree polynomial to→ the 100 points shown on the graph on page 39. →

	A	B	C	D	E	F
57		**+17.8371375215022+53.0912733397568*X-59.5706026033222*X^2+26.9864238073324…**				
58		**+1.37678894596316*X^2*Y+0.770994294857225*Y^4-3.55348562565369*X*Y^3-…**				
59		**+0.00381625498017175*Y^6-0.00587521503621247*X*Y^5-0.00655490897641504*X^2*…**				
60		**=SUM(B57:B59)**				

Lastly, use a **SUM()** function to add up each of the fragments to determine the value of the complete equation.

1-Dimensional Data Modeling via Polynomials

The chart below describes the functions for computing a best fitting least squares polynomial curve to a set of data points.

Where $y = a_n x^n + \ldots + a_2 x^2 + a_1 x + a_0$

=POLYSTR(*x_1:x_{99},y_1:y_{99},n,x$*)

=POLYVAL(*x_1:x_{99},y_1:y_{99},n,x*)

=POLYINDEX(*x_1:x_{99},y_1:y_{99},n*)

x_1:x_{99},y_1:y_{99}=Independent and dependent data point ranges which specify from 2 to 99 data points *(x_1,y_1), (x_2,y_2), (x_3,y_3),…, (x_m,y_m)*. Each range can be either a single row or single column of numbers. In the spreadsheet below, the independent (x) range is from cell A1 to A5, and the dependent (y) range is from cell B1 to B5.

n = the degree of the computed polynomial equation (from 1 to 8). However, if *m* is the number of (x,y) points and $n \geq m$, the function will compute a polynomial of degree *m*-1.

x = the value of the independent variable.

*x$* = the cell address (enclosed in quotes) of the independent variable such as "$E$1".

POLYSTR returns the equation of an *nth*-degree polynomial which fits the data in the spreadsheet. Cell B7 below contains the formula =POLYSTR($A$1:$A$5,$B$1:$B$5,2,"$E$1") which returns a string representation of the equation of the 2nd-order polynomial which best fits the data in the spreadsheet. To obtain a "live" function: (1) Select **Edit Copy…,** (2) Move the pointer to a different cell and select **Edit Paste Special…,** (3) Click the **Values** option button and then click OK, and (4) Insert an equals sign ("=") at the beginning of the equation.

POLYVAL returns the value of an *nth*-degree polynomial which best fits the data in the spreadsheet for the given value of x. Cell B8 below contains the formula =POLYVAL($A$1:$A$5,$B$1:$B$5,2,72) which returns the value of the 2nd degree polynomial which fits the data in the spreadsheet where x = 72.

POLYINDEX returns the index of an nth-degree least-squares polynomial of the specified degree. Cell B9 below contains the formula =POLYINDEX($A$1:$A$5,$B$1:$B$5,2) which returns the index of the 2nd-order polynomial equation which fits the points in the spreadsheet. An index of 1 is a perfect fit.[42]

The **POLY.XLS** worksheet from your EndResult® **Examples** disk is shown below.

Note: To sort your (x,y) points so that the x values are in either ascending or descending order, select the table of (x,y) points and use the Data Sort… → command.

	A	B	C	D	E	F
1	20	81.9		X=	72	
2	40	83.1				
3	60	84				
4	80	84.6325				
5	100	85.0302				
6						
7 (=POLYSTR→)	y=	-3.3430357E-4*$E$1^2+0.0790809*$E$1+80.4586200				
8 (=POLYVAL→)	y=	84.41942				
9 (=POLYINDEX→)	index =	.999933				

42 For a discussion of the potential problems of trying to obtain a perfect fit see page "Curve-17" and "Curve-18".

1-Dimensional Data Modeling via Derivatives

The chart below describes the functions for computing the first derivative of a least squares polynomial which is fit to a set of data points.

Where $y' = a_{n-1}x^{n-1} + \ldots + a_2x^2 + a_1x + a_0$

=DERIVSTR *(x_1:x_{99},y_1:y_{99},n,x$)*

=DERIVVAL (x_1:x_{99},y_1:y_{99},n,x)

=DERIVINDEX [1]

x_1:x_{99},y_1:y_{99}=Independent and dependent data point ranges which specify from 2 to 99 data points *(x_1,y_1), (x_2,y_2), (x_3,y_3),…, (x_m,y_m)*. Each range can be either a single row or single column of numbers. In the spreadsheet below, the independent (x) range is from cell A1 to A5, and the dependent (y) range is from cell B1 to B5.

n = the degree of the computed polynomial from which the derivative is taken (from 1 to 8). However, if *m* is the number of (x,y) points and $n \geq m$, the function will compute a polynomial of degree *m*-1.

x = the value of the independent variable.

*x$* - the cell address (enclosed in quotes) of the independent variable such as "$E$1".

DERIVSTR returns the equation of the derivative of the *nth*-degree polynomial which fits the data in the spreadsheet. Cell B7 below contains the formula =DERIVSTR($A$1:$A$5,$B$1:$B$5,2,"$E$1") which returns a string representation of the equation of the derivative of the 2nd-order polynomial which best fits the data in the spreadsheet. To obtain a "live" function: (1) Select **Edit Copy…,** (2) Move the pointer to a different cell and select **Edit Paste Special…,** (3) Click the **Values** option button and then click OK, and (4) Insert an equals sign ("=") at the beginning of the equation.

DERIVVAL returns the value of the derivative of an *nth*-degree polynomial which best fits the data in the spreadsheet for the given value of x. Cell B8 below contains the formula =DERIVVAL($A$1:$A$5, $B$1:$B$5,2,72) which returns the value of the derivative of the 2nd degree polynomial which fits the data in the spreadsheet where x = 72.

DERIVINDEX returns the index of an nth-degree least-squares polynomial of the specified degree. Cell B9 below contains the formula =DERIVINDEX($A$1:$A$5,$B$1:$B$5,2) which returns the index of the 2nd-order polynomial equation which fits the points in the spreadsheet. An index of 1 is a perfect fit.[43]

The **DERIV.XLS** worksheet from your EndResult® **Examples** disk is shown below.

Note: To sort your (x,y) points so that the x values are in either ascending or descending order, select the table of (x,y) points and use the Data Sort… → command.

	A	B	C	D	E	F
1	20	81.9		X=	72	
2	40	83.1				
3	60	84				
4	80	84.6325				
5	100	85.0302				
6						
7 (=DERIVSTR→)	y'=	-6.6860714E-4*$E$1+0.0790809				
8 (=DERIVVAL→)	y'=	0.030941				
9 (=DERIVINDEX→)	index =	.999933				

The **OPTLDALO.XLS** worksheet (provided on your EndResult® **Pre-defined Spreadsheet Solutions** disk) demonstrates a use of the add-in derivative functions.

43 For a discussion of the potential problems of trying to obtain a perfect fit, see page "Curve-17" and "Curve-18".

2-Dimensional Data Modeling via Polynomials

The POLY2DVAL function is used to model the data in a 2-dimensional table. POLY2DVAL uses polynomial curve fits to interpolate between table values. When modeling non-linear data, POLY2DVAL can estimate “in-between” values more accurately than INTERP2D.

The **POLY2D.XLS** worksheet from your EndResult® **Examples** disk is shown below. Cells C8 to G11 contain enthalpy values for pressures from 2000 to 2400 psia and temperatures from 800°F to 875°F. For example, the table shows us that the enthalpy of 850°F, 2200 psia steam is 1363.3 Btu/Lb.

The POLY2DVAL function requires five arguments, =POLY2DVAL (*table_range, horiz_deg, vert_deg, horiz_val, vert_val*).

Argument #1 The first argument is the table range. In the example below, the table range is from cell B7 to G11. Your table must include from 3 to 101 columns and from 3 to 101 rows.

Arguments #2-5 The name of argument #2, #3, #4, and #5 appears in cells B2 through B5 and an example value for each argument appears in cells D2 through D5.

	A	B	C	D	E	F	G
1							
2		Maximum horizontal degree		3	(from 1 to 8)[44]		
3		Maximum vertical degree		3	(from 1 to 8)[44]		
4		Horizontal value		2250	(from 2000 to 2400 in table below)		
5		Vertical value		865	(from 800 to 875 in table below)		
6			<---------------- Pressures ---------------->				
7		(blank)	2000	2100	2200	2300	2400
8	I	800	1335.4	1329.3	1323.1	1316.7	1310.1
9	Temp.	825	1354.9	1349.4	1343.7	1338.0	1332.1
10	I	850	1373.5	1368.4	1363.3	1358.1	1352.8
11		875	1391.3	1386.7	1382.0	1377.2	1372.4
12							
13		Estimated enthalpy		1372.159			

The example worksheet uses the POLY2DVAL function to estimate the enthalpy of 2250 psia, 865°F steam. Cell D13 above contains the formula =POLY2DVAL($B$7:$G$11,$D$2,$D$3,$D$4,$D$5). As shown above, the enthalpy computed by POLY2DVAL is 1372.159 Btu/Lb which is only slightly different from the actual enthalpy of 1372.16265 Btu/Lb.

44 For a discussion of the potential problems of trying to obtain a perfect fit, see page “Curve-17” and “Curve-18”.

2-Dimensional Data Modeling via Interpolation

The INTERP2D function is used to model the data in a 2-dimensional table. INTERP2D uses double interpolation to interpolate between table values. The **INTERP2D.XLS** worksheet from your EndResult® **Examples** disk is shown below. Cells C6 to G9 contain enthalpy values for pressures from 2000 to 2400 psia and temperatures from 800°F to 875°F. For example, the table shows us that the enthalpy of 850°F, 2200 psia steam is 1363.3 Btu/Lb.

The INTERP2D function requires three arguments, =INTERP2D *(table_range, horiz_val, vert_val)*.

Argument #1 The first argument is the table range. In the example below, the table range is from cell B5 to G9. Your table must include at least 2 rows and 2 columns (of numerical data).

Arguments #2 & #3 An example value for arguments #2 and #3 (i.e. *horizontal* and *vertical value*) appears in cells D2 and D3 respectively.

Note: INTERP2D will even work with an incomplete table. For example, if cell G6 is blank, INTERP2D will still interpolate between the remaining points.

	A	B	C	D	E	F	G
1							
2		Horizontal value		2250	(from 2000 to 2400 in table below)		
3		Vertical value		865	(from 800 to 875 in table below)		
4			<---------------- Pressures ---------------->				
5		(blank)	2000	2100	2200	2300	2400
6	I	800	1335.4	1329.3	1323.1	1316.7	1310.1
7	Temp.	825	1354.9	1349.4	1343.7	1338.0	1332.1
8	I	850	1373.5	1368.4	1363.3	1358.1	1352.8
9		875	1391.3	1386.7	1382.0	1377.2	1372.4
10							
11		Estimated enthalpy		1372.058			

The example worksheet uses the INTERP2D function to estimate the enthalpy of 2250 psia, 865°F steam. Cell D11 above contains the formula =INTERP2D($B$5:$G$9,$D$2, $D$3). As shown above, the enthalpy computed by INTERP2D is 1372.058 Btu/Lb which is only slightly different from the actual enthalpy of 1372.16265 Btu/Lb.

Although INTERP2D is not as accurate as POLY2DVAL for in-between points, INTERP2D is exactly correct for the points included in the table and it executes faster than POLY2DVAL.

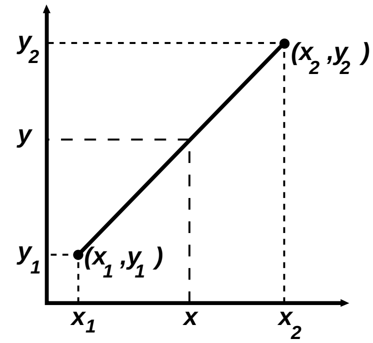
The **OILVISC.XLS** worksheet (provided in your EndResult® **Pre-defined Spreadsheet Solutions** disk) demonstrates a use of the INTERP2D function.

Two-Point Functions

The following functions are helpful in situations when you have only two data points.

Simple Interpolation Between Two Points

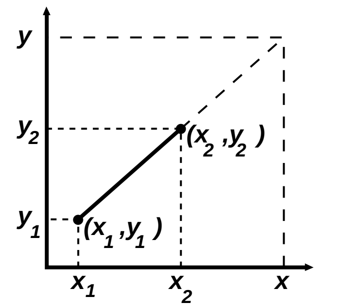
INTERP uses linear interpolation to determine the value of a line which passes through the (x_1,y_1) and (x_2,y_2) coordinates for the given value of x. For example, to obtain the value of a line which passes through the (0,10) and (100,3300) coordinates at the point x = 72, enter INTERP(0,10,100,3300, 72) and your answer will be 2378.8.



$$\textbf{if} \quad x_1 \le x \le x_2 \text{, then}$$
$$y = \mathrm{INTERP}(x_1, y_1, x_2, y_2, x)$$

Simple Extrapolation From Two Points

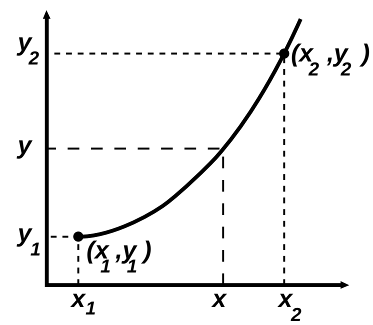
EXTRAP uses linear extrapolation to determine the value of a line which passes through the (x_1,y_1) and (x_2,y_2) coordinates for the given value of x. For example, to obtain value of a line which passes through the (0,10) and (100,3300) coordinates at the point x = 250, enter EXTRAP(0,10,100,3300, 250) and your result will be 8235.



$$\textbf{if} \quad x \le x_1 \text{ or } x \ge x_2 \text{, then}$$
$$y = \mathrm{EXTRAP}(x_1, y_1, x_2, y_2, x)$$

Square Curve Modeling Between Two Points

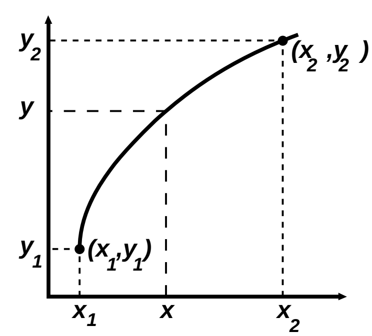
SQRXYXY returns the value of the square curve which passes through the (x_1,y_1) and (x_2,y_2) coordinates for the given value of x. For example, to obtain the value of the square curve which passes through the (0,10) and (100,3300) coordinates at the point x = 72, enter =SQRXYXY(0,10,100, 3300,72) and your answer will be 1715.536.



$$y = \mathrm{M}\,(\%x)^2 + \mathrm{B}$$
$$y = \mathrm{SQRXYXY}(x_1, y_1, x_2, y_2, x)$$

Square Root Curve Modeling Between Two Points

SQRTXYXY returns the value of the square root curve which passes through the (x_1,y_1) and (x_2,y_2) coordinates for the given value of x. For example, to obtain the value of the square root curve which passes through the (0,10) and (100,3300) coordinates at the point x = 72, enter =SQRTXYXY(0,10,100, 3300,72) and your result will be 2801.658.



$$y = \mathrm{M}\sqrt{\%x} + \mathrm{B}$$
$$y = \mathrm{SQRTXYXY}(x_1, y_1, x_2, y_2, x)$$

Performing Unit Conversions

You can perform unit conversions by using the ERUNITS(value, "*current units*", "*desired units*") function. By entering your "*current units*" and "*desired units*" from the list below, you can convert between any of the units shown in each category. Examples appear on the following page. Please note: (1) If you enter "pounds" or "lb", ERUNITS will assume you mean pounds mass ("lbm"); (2) To enter *pounds force,* you must specify either "pounds force" or "lbf"; and (3) The ERUNITS function converts all "pounds" and "ounces" according to the avoirdupois system of measure.

Any of the following units and abbreviations are equivalent.

calories, calorie, cal
feet, foot, ft
gallons, gallon, gal
grams, gram, g
horsepower, hp
hours, hour, hr
inches, inch, ins, in
joules, joule, J
liters, liter, L
meters, meter, m
miles, mile, mi
minutes, minute, min
newtons, newton, N
ounces, ounce, oz
pascals, pascal, Pa
poises, poise, p
poundsmass, pound, lbm, lb
poundsforce, poundf, lbf
seconds, second, sec, s
stokes, stoke, St
watts, watt, W
yards, yard, yds, yd

Any of these prefixes can precede any unit:

Prefix	Symbol	Value
mega	M	10^6
kilo	k	10^3
hector	h	10^2
deca	da	10^1
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	u	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
cubic	cu	^3
square	sq	^2

❶ Capital "C" refers to degrees Celsius (°C).

❷ Capital "F" refers to deg. Fahrenheit (°F).

❸ Capital "K" refers to Kelvin (K).

❹ Capital "R" refers to deg. Rankine (°R).

❺ May not be combined with other units.

Area
square centimeters
square feet
square inches
square kilometers
square meters
square miles
square yards

Density (mass density)
grams/cubic cm
grams/cubic meter
grams/liter
grams/milliliter
kg/cubic meter
lbm/cubic foot
lbm/cubic in
lbm/gallon
milligrams/liter
slugs/cubic foot

Energy, Work, Quantity of Heat
BTU
calories
foot-lbf
joules
kW-hr
MetricHP-hr
USHP-hr
watt-hr
watt-sec

Enthalpy
BTU/lbm
calories/gram
joules/gram
joules/kilogram
kilojoules/kg
megajoules/kg

Entropy (Specific heat)
BTU/lbm-F❷
BTU/lbm-R❹
cal/gram-C❶
joules/gram-C❶
kilojoules/kg-K❸

Force
dynes
longtons (or lton)
newtons
poundsforce (or lbf)
shorttons (or ston)

Heating Value
BTU/cubic foot
joules/cubic meter
cal/cubic meter
cal/liter
kilojoules/cubic meter

Length
centimeters
feet
inches
kilometers
meters
miles (statute)
millimeters
yards

Mass (Weight)
centigrams
grams
kilograms
milligrams
ounces
poundsmass (or lbm)
quarters
quintals
slugs

Mass flow
Kilograms/hour
lbm/hour

Power
BTU/hour
BTU/minute
BTU/second
dyne-cm/sec
ft-lbf/hr
ft-lbf/min
ft-lbf/sec
metric Horsepower (or MHP)
US Horsepower (or USHP)
joules/second
kiloBTU/hour
cal/hour
cal/minute
cal/second
kilowatts
megaBTU/hour
megajoules/hour
megaWatts
watts

Pressure (stress, etc.)
bars
centimeters H20 (at 60°F)
centimeters Hg (at 32°F)
dynes/sqcm
feet H20 (at 60°F)
feet Hg (at 32°F)
inches H20 (at 60°F)
inches Hg (at 32°F)
kilopascals
meter H20 (at 60°F)
meter Hg (at 32°F)
newtons/sq meter
pascals
lbf/sqft
lbf/sqin (or Psi)
ltons/sqft
ltons/sqin
stons/sqft
stons/sqin

Specific Volume
cubic cm/gram
cubic meter/gram
liter/gram
milliliter/gram
cubic meter/kg
cubic foot/lbm
cubic in/lbm
gallon/lbm
cubic foot/slug

Speed (linear)
centimeters/second
feet/hour
feet/minute (or FPM)
feet/second (or FPS)
kilometers/hour
kilometers/minute
kilometers/second
meters/minute
meters/second
miles/hour (or MPH)
miles/minute

Temperature
C❶
F❷
K❸
R❹

Time
seconds, minutes
hours, days

Thermal Conductivity
BTU/hr-ft-F❷
W/m-K❸

Viscosity (absolute)
centipoises
dyne-second/sqcm
grams/sec-cm
kg/m-hr
lbm/sec-ft
lbf-sec/sqft
lbf-sec/sqin
pascal-seconds
poises

Viscosity (kinematic)
stokes
centistokes
Redwood1 (Redwood No. 1) ❺
sqft/sec
sqm/sec
SSU (Second Saybolt Universal) ❺
SSF (Seconds Saybolt Fural) ❺

Volume
barrels (42 gallons)
cubic centimeters
cubic feet
cubic inches
cubic meters
cubic millimeters
cubic yards
gallons (US liquid)
kiloliters
liters
microliters
milliliters
pints (US liquid)
quarts (US liquid)

Volume flow
cubic centimeters/second
cubic feet/day
cubic feet/hour
cubic feet/minute
cubic feet/second
cubic inches/second
cubic yards/minute
gallons/hour
gallons/minute
liters/minute
liters/second

Example 1: To convert 300 cm^3/second to liters/second, simply enter *any* of the following:

=ERUNITS(300,"cubic centimeters per second","liters per minute")
=ERUNITS(300,"centimeter^3/second","liter/minute")
=ERUNITS(300, "cucm/sec","L/min")
=ERUNITS(300, "cm^3/sec","L/min")

Example 2: To convert 50 BTU/lb °F to kJ/kg-K, simply enter *either* of the following:

=ERUNITS(50,"BTU/poundmass-F","kilojoules/kilogram-K")

=ERUNITS(50,"BTU/lbm-F","kJ/kg-K")

When entering your "*current units"* and "*desired unit"*:

(1) You *MUST* enter your units in quotes.
(2) Hyphens should be included as shown on page 49.
(3) Hyphens have *higher* precedence than division ("/") symbols. For example, you can enter units like "kJ/(kg-K)" by simply typing in "kJ/kg-K". Be sure to use parentheses where necessary to insure that ERUNITS will interpret your units correctly.
(4) Spaces are *optional*.
(5) Legal operators include:

"()" for grouping	"/" or "per" for division
"-" for multiplication	"^" for power

The ERUNITS function analyzes each unit as a mathematical formula. For example, all of the following are equivalent and can be interconverted using ERUNITS:

kg-m/s^2 newton joule/m watt-s/m
(Newton)(kg-m/s^2)/(watt-s/m)

Moreover, all of the following units would be read as being equal:

m-m	m^2	(m)(m)	(m)m	(m)-m
(m^2)	(m)^2	(1/m^-2)	(1/m^-2.0)	etc.

If you want to know the conversion factor which ERUNITS is using to perform a particular conversion, simply convert the value 1. (For example, =ERUNITS(1,"Lbm","kg") returns the conversion factor .45359237.)

If you enter an ERUNITS function and the cell returns "#N/A", you can move the cell pointer to the cell and select **"EndResult®"** from the Microsoft® Excel **Help** menu to display a brief explanation for why the error occurred.